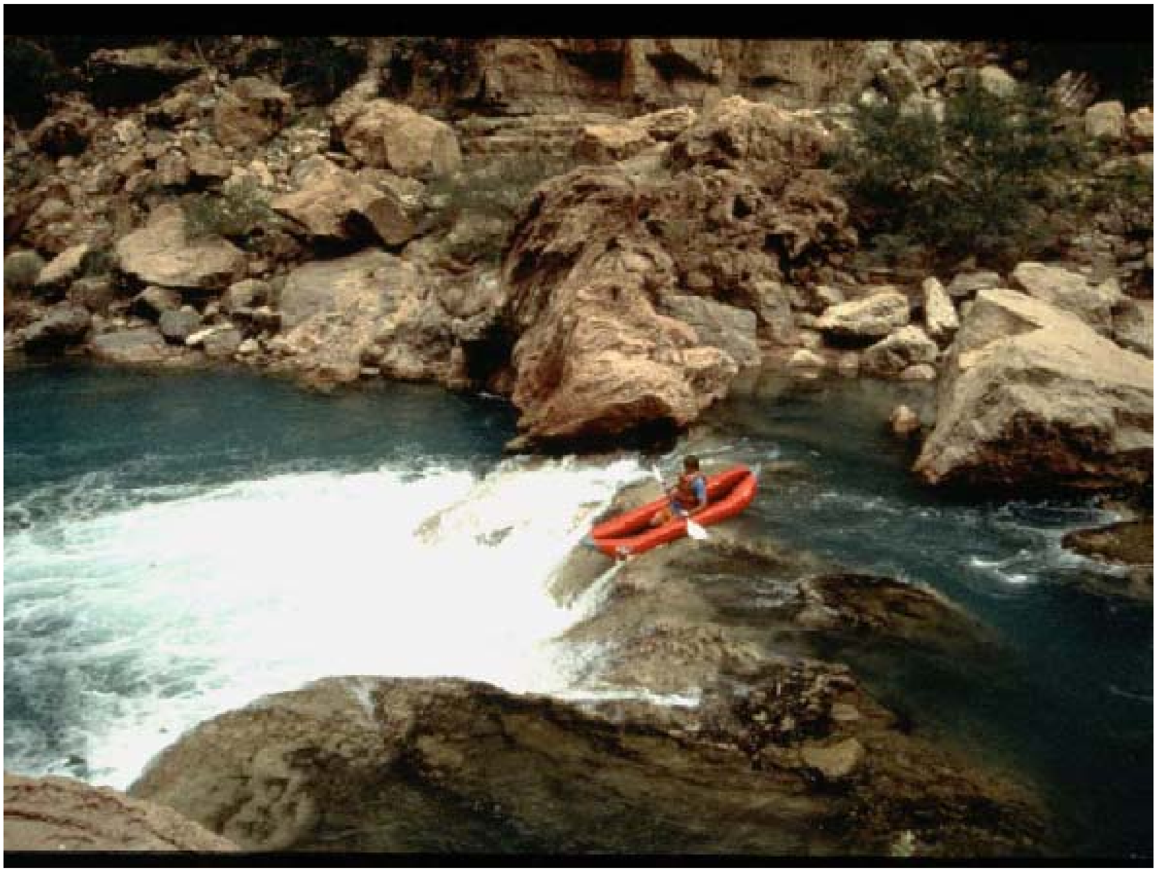
Stock Assessment and Fisheries Monitoring Activities in the Little Colorado River within Grand Canyon during 2006



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by

David R. Van Haverbeke and Dennis M. Stone

U. S. Fish and Wildlife Service

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EXECUTIVE SUMMARY

The Grand Canyon Monitoring and Research Center (GCMRC) determined that a rigorous stock assessment program for fishes in the Little Colorado River (LCR) was a priority in 2000. As a result, since 2000, the U.S. Fish and Wildlife Service (USFWS) has been contracted by GCMRC to conduct stock assessment and monitoring activities in the lower 13.57 river kilometers (rkm) of the LCR. As a continuation of this work, during the spring and fall of 2006, four monitoring trips were conducted: (1) 31 March to 7 April, (2) 25 April to 4 May, (3) 19 to 28 September, and (4) 19 October to 26 October. The primary goal of these trips was to obtain stock assessment information of the humpback chub (*Gila cypha;* [HBC]) in the lower 13.57 km of the LCR.

Also in 2006, GCMRC contracted USFWS to conduct an additional HBC stock assessment in upper perennial reaches of the lower LCR between a travertine structure known as Lower Atomizer Falls (13.57 rkm) and Blue Springs (21 rkm). Two monitoring trips occurred from 23 to 26 May, and from 28 June to 3 July, 2006. This portion of the lower perennial LCR has become of special interest because translocation efforts have now established HBC above a travertine structure known as Chute Falls (14.1 rkm). In August 2003, 283 HBC (50 to 100 mm) were translocated to above Chute Falls at 16.1 rkm, followed by another 300 in July 2004, and finally by another 567 fish in July 2005 (Stone and Sponholtz 2004, Stone 2006). The primary objective of this year's study was to conduct mark-recapture population abundance estimates of HBC residing above Lower Atomizer Falls (13.57 rkm). The effort was intended to compliment the population abundance efforts that have occurred since fall of 2000 below rkm 13.57. Although HBC have long been known to inhabit the reach of LCR between the top of Lower Atomizer Falls (13.57 rkm) and the base of Chute Falls (14.1 rkm), this stretch of river has never been included in previous LCR population abundance efforts since 2000 because of prohibiting logistics. Finally, there has been great interest in obtaining population abundance estimates for the translocated HBC now residing above Chute Falls (14.1 rkm).

Also presented on all the trips in this report are summary data gathered relating to physical parameters, fish captures, species composition, length frequency, catch per effort (CPE), sexual condition, predation, and external parasite occurrence.

Spring Trips (Confluence to the base of Lower Atomizer Falls)

The two spring trips were primarily used to conduct mark-recapture efforts to estimate the abundance of HBC ≥ 150 mm total length (TL) in the lower 13.57 rkm of the LCR. The results of the spring mark-recapture efforts indicate that there were 2,261 (SE = 285) HBC ≥ 150 mm in the lower 13.57 rkm of the LCR during the spring of 2006. Of these fish, it was estimated that there were 1,339 (SE = 249) HBC ≥ 200 mm. In addition, it was estimated that there were 12,295 bluehead sucker (SE = 4, 495) ≥ 184 mm inhabiting the LCR during the spring of 2006.

During the first spring trip, the LCR was at the end of a minor flooding event. Turbidity abated from 570 to 61 nephelometric turbidity units (NTUs), and daily afternoon water temperatures averaged 17.9 ^{o}C. During the second spring trip, the LCR was at base flow and blue. Turbidities ranged between 14.5 and 26.5 NTUs and daily afternoon water temperatures averaged 20.1 ^{o}C.

During both spring trips combined, a total of 987 hoop net sets were deployed, yielding 23,186 hours of fishing effort. A total of 10,458 fish were captured, of which 4,863 were HBC. Catch per effort (CPE) for HBC was 0.21 fish/net-hour. Nonnative fishes comprised 26% of the catch, most of these being fathead minnow (*Pimephales promelas*). A total of 177 male and 10 female captured HBC were ripe. Twenty-five ripe flannelmouth sucker (*Catostomus latipinnis*) and 648 ripe bluehead sucker (*C. discobolus*) were captured. Fourteen black bullheads (*Ameiurus melas*), 5 channel catfish (*Ictalurus punctatus*), and 1 brown trout (*Salmo trutta*) were examined for stomach contents. No direct predation on HBC was detected, but 5 of the predators had fish remains in their stomachs. In addition, 16 adult HBC and 5 adult bluehead sucker were captured with presumed catfish bites on them. Percent occurrence of the external anchorworm (*Lernaea cyprinacea*) on HBC was 7.9%.

Fall Trips (Confluence to the base of Lower Atomizer Falls)

The two fall trips were primarily used to conduct mark-recapture efforts to estimate the abundance of HBC ≥ 150 mm in the lower 13.57 kilometers of the LCR. The results of the fall mark-recapture effort indicate that there were 1,925 (SE = 361) HBC ≥ 150 mm in the lower 13.57 rkm of the LCR during the fall of 2006. Of these fish, it is estimated that there were 1,347 (SE = 342) HBC ≥ 200 mm.

During the first fall trip, the LCR was nearing base flows from a preceding series of flooding events. Turbidities abated from 29,136 to 931 NTUs, and daily afternoon water temperatures averaged 19.1 ^{o}C. During the second fall trip, the LCR was again nearing base flows after experiencing another flooding event. Turbidities ranged from 59,296 to 8,624 NTUs and daily afternoon water temperatures averaged 15.8 ^{o}C.

During both fall trips combined, a total of 1,080 hoop net sets were deployed, yielding 25,132 hours of fishing effort. A total of 1,033 fish were captured, of which 717 were HBC. CPE for HBC was 0.029 fish/net-hour. Nonnative fishes comprised 15.8% of the catch. Eleven ripe male HBC, 5 ripe male bluehead sucker, and 2 ripe male flannelmouth sucker were captured. Seventy-nine black bullhead were examined for stomach contents, 5 of which had fish remains in their stomachs; only 1 speckled dace was identifiable in the stomachs. In addition, 15 adult HBC and 2 bluehead sucker had presumed catfish bites on them. Percent occurrence of the external anchorworm (*Lernaea cyprinacea*) on HBC was 4.5%.

Chute Falls trips (Lower Atomizer Falls to 18.1 rkm)

The two Chute Falls trips were primarily used to conduct mark-recapture efforts to estimate the abundance of HBC ≥ 125 mm between the top of Lower Atomizer Falls and the base of Chute Falls (13.57 to 14.1 rkm), and from the top of Chute Falls to 18.1 rkm in the LCR, where sampling activities ended. The results of the effort from Lower Atomizer Falls to Chute Falls (lower reach) indicated that there were 707 (SE = 42) HBC ≥ 125 mm during the late May to early July of 2006. Of these fish, it is estimated that there were 328 (SE = 25) HBC ≥ 150 mm, and 206 (SE= 18) HBC ≥ 200 mm. The results of the effort from above Chute Falls (14.1 rkm) to 18.1 rkm (upper reach) indicated that there were 440 (SE = 35) HBC ≥ 125 mm during the late May to early July of 2006. Of these fish, it is estimated that there were 255 (SE = 11) HBC ≥ 150 mm, and 125 (SE= 15) HBC ≥ 200 mm.

During both Chute Falls trips, the LCR was running near base flow. On the first Chute Falls trip, turbidities ranged from 2.1 to 3.5 NTUs, and daily afternoon water temperatures averaged 20.4 ^{o}C. During the second Chute Falls trip, turbidities ranged from 1.2 to 1.5 NTUs and daily afternoon water temperatures averaged 21.1 ^{o}C. Mean dissolved CO_2 was 220 (SE = 5.0) mg/l during the first trip and 229 (SE = 4.91) mg/l during the second trip.

During both trips combined, a total of 299 hoop net sets were deployed, yielding 6,993 hours of fishing effort. A total of 13,954 fish were captured, of which 1,430 were HBC, and 12,263 were speckled dace (*Rhinichthys osculus).* CPE for HBC was 0.179 fish/net-hour. Nonnative fishes comprised 1.9% of the catch. Sixty-four ripe male HBC and 1 ripe female HBC were captured. Three black bullhead had fish remains in their stomachs (speckled dace or unidentifiable fish). Percent occurrence of the external anchorworm (*Lernaea cyprinacea*) on HBC was 0.05%.

INTRODUCTION

With the passage of the Grand Canyon Protection Act in 1992, the Glen Canyon Dam Adaptive Management Program was initiated, with the Adaptive Management Work Group (AMWG) being responsible for defining management objectives associated with the resources downstream of Glen Canyon Dam, and making recommendations for the development of a long-term monitoring program to assess those resources. The Grand Canyon Monitoring and Research Center (GCMRC) is responsible for implementing the long-term monitoring program and assuring that it is fulfilling the needs of the AMWG. The humpback chub (*Gila cypha*; HBC) is particularly important due to its status as a federally listed endangered species (U.S. Office of the Federal Register 32:48 [1967]:4001).

A tremendous amount of research has been conducted to gain a better understanding of HBC in Grand Canyon over the last 20 years. Some of this work has reported on population status (Kaeding and Zimmerman 1983, Valdez and Ryel 1995, Douglas and Marsh 1996), while other studies have focused on natural history and ecology (e.g., Robinson et al. 1998, Gorman and Stone 1999, Clarkson and Childs 2000). Because the AMWG has a need to effectively assess the impacts of the operation of Glen Canyon Dam on HBC and to evaluate whether fish management objectives in Grand Canyon are being met, GCMRC initiated a program in 2000 that focused on stock assessment and long-term monitoring of Grand Canyon fishes.

GCMRC's long-term monitoring strategy for the Little Colorado River (LCR) HBC population is essentially a four pronged approach:

1. Annual spring and fall HBC abundance assessments in the lower 13.57 km of the LCR.

2. Annual spring HBC relative catch rate comparisons in the lower 1200 m of the LCR.

3. Annual spring/summer HBC relative catch rate comparisons in the LCR Inflow (mainstem Colorado River mile 57 to 65.4).

4. Annual assessment of the overall LCR HBC population abundance and recruitment utilizing the age structured mark-recapture model (ASMR) developed by GCMRC (Coggins et al. 2006).

Each of these programs is designed to complement each other, providing a comprehensive view of the dynamics of the LCR HBC population.

In order to address item 1 above, in October and November 2000 the USFWS undertook an effort to estimate the fall abundance of HBC in the LCR (Coggins and Van Haverbeke 2001). Briefly, the strategy was to obtain a closed population estimate of HBC in the LCR via a two pass mark-recapture effort. Because of the success of this initial effort, this strategy was expanded into mark-recapture efforts during the spring and fall of 2001, 2002, 2003, 2004, and

2005 (Van Haverbeke and Coggins 2003, Van Haverbeke 2003, 2004, 2005, 2006). In 2006, GCMRC again contracted the USFWS to continue these efforts to obtain spring and fall abundance estimates of HBC in the lower 13.57 rkm of the LCR. In addition, GCMRC requested that USFWS obtain an abundance estimate of HBC above 13.57 rkm in the LCR during the summer of 2006.

One important element of the spring and fall efforts is that they were designed to be comparable to the historical population abundance estimates of HBC in the LCR provided by Douglas and Marsh (1996). Like Douglas and Marsh (1996), our approach is to obtain closed population abundance estimates in the LCR via fishing the entire lower 13.57 km of the LCR with hoop nets deployed from three separate camp locations. However, largely because of funding constraints, our efforts only provide closed population estimates during the spring and fall of each year, rather than on a monthly basis year round as was obtained by Douglas and Marsh (1996). Nevertheless, within a given set of spring and fall months, and within a given size class of fish (≥ 150 mm), our estimates are considered comparable to the estimates of Douglas and Marsh (1996). Our spring estimate is timed to coincide with the peak of HBC spawning within the LCR and therefore provides GCMRC with a reliable measure of the annual spawning magnitude. Our fall estimate is aimed primarily at providing an estimate of the abundance of HBC ≥ 150 mm rearing or "overwintering" in the LCR. In addition, the fall monitoring activities provide researchers with an early indication of the success of the annual production of age-0 HBC.

This year's mark-recapture effort above rkm 13.57 (Chute Falls effort) represents the first mark-recapture effort conducted in this reach of the river. This upper portion of the perennial lower LCR corridor became of interest after a series of recent translocation efforts that moved 1,150 HBC (50 to 100 mm) from near the confluence region of the LCR to above a travertine structure called Chute Falls (Stone and Sponholtz 2004, Stone 2006). Because of difficult logistics, the annual spring and fall mark recapture efforts are only inclusive HBC inhabiting the LCR up to 13.57 rkm (below Lower Atomizer Falls). Previous to now, biologists have had to rely upon extrapolation to estimate the abundance of HBC inhabiting the LCR from above Lower Atomizer Falls to the base of Chute Falls (13.57 to 14.1 rkm). This procedure can be performed by using the mean number of HBC/rkm obtained in population estimates in the lower 13.57 rkm. Thus, the 2006 mark-recapture efforts above 13.57 rkm are not only inclusive of the abundance of the HBC population translocated above Chute Falls, but also represent the first real estimate of the abundance of HBC between Lower Atomizer Falls and the base of Chute Falls.

OBJECTIVES

The primary objective of this program is to obtain information for the stock assessment of HBC (i.e., to monitor for annual changes in the abundance of adult HBC in the LCR). In addition, these trips provide opportunities to characterize the natural history and ecology of the LCR fish community. Therefore, all species of native and non-native fish are monitored. The specific objectives for 2006 were:

1. Obtain spring (April/May) and fall (September/October) 2006 population estimates of HBC ≥ 150 mm in the lower 13.57 rkm of the LCR.

2. Obtain a late May/June 2006 population estimate of HBC ≥ 100 mm from the reaches of LCR between 13.57 and 14.1 rkm (from above Lower Atomizer Falls to the base of Chute Falls), and above Chute Falls (in this case from 14.1 to 18.1 rkm).

3. Collect data in support of GCMRC stock assessment models. Specifically, our data and results will be incorporated into Age-Structured Mark-Recapture (ASMR) models that make full use of the historical database to estimate long-term population and recruitment trends of HBC (e.g., Coggins et al. 2006).

In addition to the above stated objectives, information is also presented on physical parameters of the LCR, effort and catch compositions, species compositions, length frequency distributions, sexual conditions, predation, and parasites.

METHODS

Trips and Participating Personnel

Six sampling trips were carried out in the LCR during 2006. The spring trips were from 31 March to 7 April (April trip), and 25 April to 4 May (May trip); the fall trips were from 19 to 28 September, and 19 to 26 October; the Chute Falls trips were from 23 to 26 May (May trip), and 28 June to 3 July (June trip). Note that the dates for the field trips are only inclusive of actual fishing days (i.e., from the date nets are deployed in the water to the dates they are pulled out of the water), and do not include fly-out day. Participating field crew included personnel from USFWS, SWCA Inc., Arizona Game and Fish Department, and volunteers (Table 1).

Study Sites

All work for the spring and fall trips was conducted in the lower 13.57 rkm of the LCR, below a large travertine structure called Lower Atomizer Falls (Figure 1). During the course of each spring and fall trip, the LCR was divided into three contiguous ~5 rkm reaches, with base camps located within each reach. River kilometer within the LCR began with zero at the confluence with the Colorado River. Base camps were established for the Boulders, Coyote and Salt reaches at 1.9, 9.0, and 10.4 rkm, respectively. Each reach was divided into three sub-reaches. Boulders reach was divided into three sub-reaches: 0.0 to 1.8 rkm (Confluence to above Jump Off Rock), 1.8 to 3.0 rkm (above Jump Off Rock to Powell Canyon), 3.0 to 5.0 rkm (Powell Canyon to 5.0 rkm). Coyote reach was divided into three sub-reaches: 5.0 to 6.5 rkm (5.0 to above White Spot), 6.5 to 8.0 rkm (above White Spot to Redbud Canyon), and 8.0 to 9.6 rkm (Redbud Canyon to House Rock). Salt reach was divided into three sub-reaches as follows: 9.6 to 11.2 rkm (above House Rock to Hell Hole), 11.2 to 12.3 rkm (Hell Hole to Triple Drop), 12.3 to 13.57 rkm (Triple Drop to Lower Atomizer Falls).

During the May and June Chute Falls trips, the LCR was separated into a lower reach from the top of Lower Atomizer Falls (13.57 rkm) to the base of Chute Falls (14.1 rkm) and an upper reach from the top of Chute Falls (14.1 rkm) to 18.1 rkm (Figure 1).

Gear

During the spring and fall trips, unbaited hoop nets (0.5 - 0.6 m diameter, 1.0 m length, 6 mm [1/4”] mesh, with a single 0.1 m throat) were deployed to sample fishes. Sixty hoop nets were fished throughout each of the three reaches during each trip. Nets were distributed throughout each reach by fishing equal numbers of nets within each sub-reach (i.e., 20 nets were fished within each sub-reach). Each sub-reach was fished for three consecutive 24 hour periods (i.e., inclusive of three nights each). In addition, each hoop net was positioned in favorable habitat suspected of yielding catches of HBC. Nets were often repositioned following net checks when the catch was poor, if an alternative site was available. Shoreline distance between nets varied due to many logistical considerations; however, most nets were placed between 80 to 150 m apart, and an effort was made to roughly space nets evenly. Most nets were tied from the shorelines and set along shore or within a few meters from shore. Some nets were tied from mid-channel boulders and fished further from shore. Each net was checked and emptied of fish daily.

During the Chute Falls trips, identical hoop nets as described above were used. However, nets were all baited near their cod ends by attaching nylon mesh bags (30 x 30 cm, 6 mm mesh) filled with ~160 g AquaMax™ Grower 600 for Carnivorous Species (Purina Mills Inc., Brentwood, MO) to maximize fish captures (Stone, 2005). Nets were baited because a primary objective of the mark-recapture effort in this section of river was to mark as many fish as possible in order to more closely track translocated fish in the future. During the May trip, we sampled the reach between Lower Atomizer Falls and the base of Chute Falls with 16 baited nets, and the reach above Chute Falls to 18.1 rkm with 34 baited nets, all of which were run for three consecutive ~24 h hauls. During the June trip we deployed 17 baited nets below Chute Falls and 33 baited nets above Chute Falls for three consecutive ~24 h hauls. Many nets were re-deployed to new locations between hauls to reduce potential biases associated with catch rate differences among disparate habitats, and diminishing catch rates overtime.

For all trips, all net locations for were recorded as distance (rkm) above the confluence, side of the river (right, left, center), and nets were individually marked on photographic maps supplied by GCMRC. General habitat characteristics were recorded for the nets, including shoreline habitat, hydraulic unit, substrate, and cover type (Table 2).

Fish

Data collected for HBC, flannelmouth sucker, and bluehead sucker included total length (TL mm) and fork length, sex (male, female, undetermined), sexual condition (ripe, spent), sexual characteristics (tuberculate, breeding colors), external parasite types, and number of external parasites per fish. Typically, speckled dace were measured for TL and examined for parasites, however, because of time limitations speckled dace were often just tallied per net set, particularly above Chute Falls where they are found in high densities. All fish lengths reported in this document refer to total lengths (TL). All HBC ≥ 150 mm were scanned for a Passive Integrated Transponder (PIT) tag (Biomark, Inc.), and if lacking a tag or containing an older 400 kHz PIT tag, were injected with a new 134.2 kHz PIT tag. Native suckers and carp ≥ 150 mm on all trips were scanned for a PIT tag, and if not already tagged, were injected with a PIT tag. Stomach contents of large bodied non-native fish (primarily ictalurids and salmonids) were examined and recorded in the field. All bullhead were identified to be black bullhead (*Ameiurus melas*) in this document based on anal fin ray counts.

During the Chute Falls trips, all HBC ≥ 100 mm (rather than ≥ 150 mm) were PIT tagged, as well as examined for colored elastomer tags. The decision to PIT tag HBC at a smaller size class in the Chute Falls reaches was based on a need to track the abundance and movement of translocated fish. Also during the Chute Falls trips, fin clips were taken from 28 HBC during the May trip and 12 HBC during the June trip for genetic analyses by Dr. Connie Keeler-Foster (USFWS Dexter National Fish Hatchery and Technology Center).

Water Quality

Measured water quality parameters for the spring and fall trips included daily afternoon temperature (^{o}C) and turbidity (nephelometric turbidity units; NTUs), and were collected daily at Salt reach (~10.4 rkm). Turbidity readings were taken with a Hach 2100P Turbidimeter, Loveland, CO. During the Chute Falls trips, these measurements were taken from the Translocation Camp (16.2 rkm). In addition, dissolved CO_2 measurements were occasionally taken at the Translocation Camp between 1700 and 1900 hrs. Provisional discharge (mean daily cubic feet per second; cfs) data was downloaded from USGS gage station 0940200 (http://nwis.waterdata.usgs.gov) located on the LCR near Cameron, AZ.

Mark-Recapture Analysis and Assumptions

Two mark-recapture efforts (spring and fall) were conducted to estimate the abundance of HBC ≥ 150 mm in the lower 13.57 km of the LCR. An additional mark-recapture effort was conducted during the Chute Falls trips to estimate the abundance of HBC ≥ 100 mm between 13.57 to 18.1 rkm. Marking events occurred during the first spring trip (31 March to 7 April), during the first fall trip (19 to 28 September), and the first Chute Falls trip (23 to 26 May). Fish ≥ 150 mm (or ≥ 100 mm during the Chute Falls trip) that had not previously been tagged were injected with an individually numbered and recorded PIT tag. At the end of each marking trip, all unique HBC that had been either tagged or recaptured from previous trips were considered the marked portion of the population. Unique fish are individuals that are captured within a trip, but do not include subsequent captures of that same fish during the same trip. Recapture events occurred during the second spring trip (25 April to 4 May), during the second fall trip (19 to 26 October), and during the second Chute Falls trip (28 June to 3 July).

The target population was all HBC ≥ 150 mm (or ≥ 100 mm during the Chute Falls trips). However, the target and sampled population (i.e., the size specific component of the population that is effectively sampled) frequently differ, and it is only possible to estimate the abundance of the sampled population. Therefore, we first examined our data to define our sampled population. Bernard and Hansen (1992) suggest setting the lower boundary of the sampled population equal to the length of the smallest fish recaptured. However, we allowed for growth and measurement error that could have occurred between the marking and recapture events (~10 mm). Since our smallest recaptures during the spring and fall estimates were 152 and 158 mm, respectively, we found no reason not to provide estimates inclusive of all HBC ≥ 150 mm. The smallest recapture during the Chute Falls recapture trip was 122 mm. For this reason, we defined out sampled population at 125 mm and present abundance estimates as all HBC ≥ 125 mm. We did not truncate the upper end of our estimates in any of the studies, since the types of hoop nets used in our study have been shown to effectively capture large HBC in previous studies (Gorman and Stone 1999).

The Chapman modified Petersen (hereafter referred to as Chapman Petersen) two-sample mark-recapture model (Seber 2002) was used to estimate the abundance of the target population. Assumptions necessary for unbiased estimates of abundance using this estimator are:

1. The population is closed, with no additions or losses between marking and recapture events either through recruitment, immigration, mortality, or emigration.

2. Marking does not affect capture probability during the recapture event.

3. All HBC in the target population have an equal probability of capture during the marking event or the recapture event; or marked fish mix completely with unmarked fish prior to the recapture event.

4. Marks (tags) are not lost between the marking and recapture events.

5. All marked fish captured can be recognized from unmarked fish.

The first assumption, addressing population closure, could potentially be violated in this system since HBC in the LCR have access to the mainstem Colorado River. Additionally, the first assumption has a higher probability of being violated during the spring than during the fall mark-recapture events. HBC movement and migration is known to occur during the spring of the year (Kaeding and Zimmerman 1983; Douglas and Marsh 1996), but is thought to be at a minimum during the fall and winter months (Douglas and Marsh 1996, Valdez and Ryel 1995). We attempted to minimize the potential for violating this assumption by only allowing a short time span (less than a month) to elapse between our mark and recapture events. It was also assumed that growth related recruitment was minimized due to the short time span between the mark and recapture events. Finally, all fish captured during both mark-recapture efforts were handled with utmost care to avoid injury or stress related mortality.

If HBC emigrate from the LCR or die between sampling events, and both marked and unmarked fish are lost at a rate that is proportional to their abundance in the population, the Chapman Petersen estimator can still be used, but the population estimate will only be germane for the population during the marking event. Additionally, if HBC immigrate into the LCR between the two events, then the population estimate will only be germane for the population during the recapture event. If both additions and losses (i.e., such as immigration and emigration) occur between the events, there is no possible correction and the estimate will overestimate HBC abundance.

The issue of closure is also relevant to the Chute Falls trips. In this report, the upper reach above Chute Falls is treated as a one way closed population (i.e., independent abundance estimates of HBC are provided for the reach above Chute Falls and for the reach below Chute Falls). Although HBC have been documented moving from above Chute Falls to below, no HBC as of the date of these studies in 2006 have been documented as moving from below to above Chute Falls. In the lower reach (Lower Atomizer to Chute Falls) the population of HBC is considered as being "open" with regards to the lower 13.57 rkm of the LCR (i.e., fish have been documented moving back and forth between the lower 13.57 rkm reach and the reach between 13.57 and the base of Chute Falls). It is not known with certainty how open this reach is, because of the travertine obstructions at Lower Atomizer Falls (13.57 rkm) and Upper Atomizer Falls (13.87 rkm). However, it is assumed to be open because historically HBC have been captured in the lower contiguous LCR from the Confluence (0 rkm) to the base of Chute Falls (14.1 rkm). Prior to the translocation efforts, HBC were never documented above Chute Falls.

Kolmogorov-Smirnov tests (K-S tests) were applied to the length frequency distribution data collected during both the mark and recapture events. A change in length frequency distribution between the marking event and the recapture event could potentially occur through three mechanisms; 1) violation of closure (e.g, immigration or emigration of a size class component), 2) a behavioral response, or 3) a temporal change in the length bias of the sampling gear. The first K-S test compared the length frequency distributions of marked fish [*M*] with those captured during the recapture event [*C*]. By testing for differential length distribution between capture occasions, this test can indicate potential violation of assumptions 1 and 2. The second K-S test compared the length frequency distributions of fish marked during the marking event [*M*] with those recaptured during the recapture event [*R*]. By testing for differential capture probability among different length fish, this test functions to indicate a potential violation in assumption 3.

It was not possible to directly test the second assumption that capture and handling during the first event affected the recapture probability in the second event. However, results of the K-S tests provided indirect evidence of whether the second assumption was violated. Again, careful handling of the fish throughout the study should have minimized violations of this assumption.

The third assumption is equal capture probability of all fish. One way this assumption can be violated is if the capture gear (i.e., hoop nets) is highly size selective. To determine if the probability of capture varied due to fish size, tests were performed that applied the length frequency data collected during the mark and recapture events. The first of these was the second K-S test discussed above. Additionally, to validate whether all fish had an equal probability of capture during the marking event regardless of their size, a contingency table analysis was used to test whether the "mark rate" differed among 50 mm size categories (e.g., from 150 to 450 mm) of fish. This was performed by dividing the number of recaptured fish [R] by the number of fish captured [C] within each 50 mm size class, and comparing the results in the contingency table analysis. Similarly, a “recapture rate” can be used to validate whether all fish had an equal probability of capture during the recapture event. This was performed by dividing the number of recaptured fish [R] by the sum of the number of fish marked [M] and recaptured [R] within each 50 mm size class, and comparing the results in the contingency table analysis.

Capture probability can also differ by location (i.e., along the LCR river corridor). To minimize the deviance in our data due to spatial variability in capture probability, sampling was equally distributed throughout the entire study areas. To validate whether all fish had an equal probability of capture during the marking event regardless of their location, a contingency table analysis was used to test whether the “mark rate” differed among sampling reaches and among sub-reaches, by dividing the number of recaptured fish [R] by the number of fish captured [C] within each geographic reach, and comparing the results (Seber 2002). Similarly, a “recapture rate” can be used to validate whether all fish had an equal probability of capture among the reaches and among subreaches during the recapture event. This was performed by dividing the number of recaptured fish [R] by the number of fish marked [M] within each geographic reach, and comparing the results with contingency table analysis.

The results of all of the above tests provided supportive evidence to determine whether modifications to the Chapman Petersen estimator were necessary to minimize bias (Bernard and Hansen 1992). These modifications included stratifying the abundance estimates by length, by geographic reach, or both, if necessary. It should be noted that the tests described above do not necessarily provide conclusive evidence of particular assumption violation, but are used as supportive tools (i.e., stratifications based on length are either performed or not performed based on the test results in an effort to minimize bias).

Addressing the fourth assumption (potential tag loss) is problematic. During the spring trips of 2001, a dorsal fin punch was used as an auxiliary mark to the newly PIT tagged fish ≥ 150 mm (Van Haverbeke and Coggins 2003). Unfortunately, this type of auxiliary mark was found to be unreliable as a diagnostic tool, because of regenerated fins and confusion with injuries due to other causes. Elastomer dye tags have also been too unreliable to use as a long term secondary mark (Stone and Sponholtz 2003). As a result, we have not been able to test for tag loss because of the lack of a reliable secondary mark. Regardless, we cautiously assumed that tag loss was negligible because of the short time frame of the studies and the high retention rate of PIT tags demonstrated in bonytail (*G. elegans*) studies (Childs 2002).

The fifth assumption relates to the ability of field personnel to detect the presence of a tag in a fish. This assumption was not evaluated directly; however, our staff is trained in the proper operation of the PIT scanners and is exceedingly careful to ensure that PIT scanners are in good working order.

Abundance estimates were calculated with the formulae presented by Seber (2002) as:

$$N^* = \frac{(M+1)(C+1)}{R+1} - 1 \tag{1}$$

$$V[N^*] = \frac{(M+1)(C+1)(M-R)(C-R)}{(R+1)^2(R+2)} \tag{2}$$

Where:

N^* = the estimated number of fish in the population,

$V[N^*]$ = the estimated variance of the number of fish in the population,
M = the number of fish marked during the marking events,
C = the number of fish captured during the recapture events,
R = the number of fish recaptured from the marked population during the recapture events.

In order to estimate the abundance of HBC ≥ 200 mm for the spring and fall, the Chapman Petersen estimates of HBC ≥ 150 mm were multiplied by the proportion of fish ≥ 200 mm with the formulae presented in Seber (2002) as:

$$N_x^* = \frac{M_x + C_x - R_x}{M + C - R} N^* = P\ (N^*), \tag{3}$$

$$V[N_x^*] = N_x^{*2}\left[\frac{1}{R} + \frac{2}{R^2} + \frac{6}{R^3}\right] + \frac{N_x^*(N^* - N_x^*)}{(M + C + 1)} \tag{4}$$

Where:

P indicates the proportion of fish within a particular size class and the subscript *x* indicates fish that belong to a particular size class (e.g., ≥ 200 mm). This procedure was also used in estimating the abundances of HBC ≥ 150 mm and HBC ≥ 200 mm in the Chute Falls efforts. Note that equations 3 and 4 have been uniformly applied to all population estimates of HBC ≥ 200 mm that are presented in this report (i.e., this has resulted in some very minor changes to the variances given in USFWS reports prior to 2005). The 95% confidence limits on our abundance estimates assume a normal distribution and are appropriate given the ratios of *R*/*C* and *R*/*M* observed in the experiments (Seber 2002).

SPRING RESULTS (CONFLUENCE TO LOWER ATOMIZER FALLS)

Physical Parameters

The April trip began at the end of a freshet in the LCR. This small spate peaked at 74 cfs at the Cameron gage station on 20 March (mean daily flow peaked at 51 cfs on 21 March), and had largely subsided by the day our sampling activities began on 31 March (Figure 2). Notably, this small event was the only spate the LCR underwent during spring of 2006 (i.e., spring flooding was essentially absent this year). Turbidity abated from a high of 570 NTUs on 30 March to 61 NTUs on 6 April (Figure 3). Daily afternoon water temperatures ranged between 13.3 and 19.6 ^{o}C (mean = 17.9 ^{o}C).

Throughout the May trip the LCR was blue and at base flow (Figure 2). Turbidities ranged between 14.5 and 26.5 NTUs (mean = 19.4; Figure 3), the daily variance seemingly caused by wind disturbance (i.e., dust and sand blowing into the river). Daily afternoon water temperatures ranged from 19.1 to 20.9 ^{o}C (mean = 20.1 ^{o}C).

Effort and Catch

During both spring trips, a total of 987 hoop net sets were deployed, yielding 23,186 hours of fishing effort (Table 3). Catch per effort (i.e., total HBC captured/total net hours; CPE) of HBC captured in hoop nets was higher during the May trip (3,140 fish captured, 0.249 fish/net-hr) than during the April trip (1,723 fish captured, 0.163 fish/net-hr). Fishing effort during both trips combined produced a total catch of 10,458 fish, for all species (Table 4).

Species Composition

The dominant native species captured during both spring trips were HBC (4,863 fish; 47%) and speckled dace (1,561 fish; 15%), however, species compositions between the two trips showed some differences. HBC comprised the largest proportion of fish caught on both trips (49% and 46%; Figure 4). Bluehead sucker increased in proportion from the April trip to the May trip. Exotic species collected (in order from most to least abundant captured from both trips combined) were 2,646 fathead minnow (*Pimephales promelas*), 21 black bullhead (*Ameiurus melas*), 14 carp (*Cyprinus carpio*), 10 channel catfish (*Ictalurus punctatus*), 6 red shiner (*Cyprinella lutrensis*), 2 green sunfish (*Lepomis cyanellus*), 1 plains killifish (*Fundulus zebrinus*), and 1 brown trout (*Salmo trutta*). No rainbow trout (*Oncorhynchus mykiss*) were captured. During April, 32% of the fish captured were nonnative; while during May 23% of the fish captured were nonnative. Most of these nonnative fish were fathead minnow. The single brown trout (405 mm) was captured in Salt reach at 11.2 rkm. The 2 green sunfish (100 and 71 mm) were taken in Coyote reach at 8.24 and 9.13 rkm. Adult carp and channel catfish, which seldom enter hoop nets, were likely under-represented.

Length Frequency Distributions and Catch

Length frequency distributions for all HBC captured on both trips are shown in Figure 5. Notably, a large number (3,588 fish) of HBC in the 70 to 140 mm size class were captured. These were assumed to be largely composed of the 2005 cohort, suggesting good over-winter survivorship of that cohort. As a side note there were no floods in the LCR > 1,000 cfs (mean daily flow), between 19 March 2005 through our spring 2006 sampling activities; which likely contributed to this apparent high survivorship. Overall, more HBC were captured during the May trip (3,140 fish) than during the April trip (1,723 fish), largely due to higher catches of HBC in the 70 to 140 mm size class during May. The higher catches in May were likely result of blue water conditions, warmer water temperatures, and deployment of a higher number of net sets compared to April. Cumulative length frequency distributions for HBC (Figure 6) show some discrepancies in the relative frequency of size classes among reaches. For both trips combined, more HBC < 150 mm were captured in the Boulder (1,354 fish) and Coyote (1,278 fish) reaches, than in the Salt reach (987 fish), indicating a typical increasing downriver catch rate trend for these juvenile fish.

Flannelmouth sucker length frequency distributions show a scattered assortment of various size classes (Figure 7). As with HBC, more flannelmouth sucker were captured during the May trip (132 fish) than during the April trip (49 fish). Most of these fish were captured in the Boulders reach (142 fish, 78% of all flannelmouth captures) or in the Coyote reach (34 fish, 19% of all flannelmouth sucker captures; Table 4), as is usual. Forty-one presumed age-0 (<100 mm) flannelmouth sucker were captured during both trips combined. All age-0 fish were captured in Boulders reach between 0.18 and, except 1 in Coyote reach at 8.45 rkm.

Bluehead sucker length frequency distributions show a group of adult fish in the 170 to 300 mm size range and another group of fish <100 mm (Figure 8). As with HBC and flannelmouth sucker, fewer bluehead sucker were captured during the April trip (135 fish) than during the May trip (1,017 fish). Most bluehead sucker were captured in the Boulders reach (515 fish, 45% of all bluehead sucker captured) or in the Coyote reach (408 fish, 35% of all bluehead sucker captures; Table 4). Three hundred and nineteen presumed age-0 (<100 mm) fish were captured. Unlike age-0 flannelmouth sucker, the age-0 bluehead sucker were distributed equally among the three reaches (107 fish in Salt, 105 in Coyote, and 107 in Boulders), and were captured between 0.39 and 13.31 rkm.

Length frequency distributions of black bullhead, carp, and channel catfish are shown in Figure 9. Black bullhead show a scattered distribution of fish from 115 to 250 mm, with 1 presumed age-0 fish (67 mm). Carp show 13 juvenile fish (122 to 169 mm), with 1 age-0 fish (85 mm). Channel catfish show 9 age-0 or age-1 fish (92 to 143 mm) and an additional large adult (475 mm). Probably under-represented in these charts are the presence of adult channel catfish and carp, which have very low catch rates in hoop nets.

Sexual Condition

During the April trip, 75 ripe HBC were captured. Sixty-eight of these were male (110 to 405 mm) and were captured between 1.32 and 13.47 rkm. The remaining 7 females (160 to 416 mm) were scattered between 2.88 and 13.52 rkm. Eight ripe male (371 to 481 mm) and 1 ripe female (466 mm) flannelmouth sucker were captured. One male was caught at 2.3 rkm, while the others were all caught at 8.68 rkm. Forty-six ripe male bluehead sucker (181 to 290 mm) between 0.38 and 11.92 rkm. Five ripe female bluehead sucker (205 to 277 mm) were captured at 2.3 and 3.55 rkm. Finally, 21 ripe fathead minnow (41 to 88 mm) were seen in the Boulders reach, all but 2 were females (although fathead minnow are not usually checked for ripeness).

During the May trip, 112 ripe HBC were captured. One hundred and nine of these were male (153 to 421 mm), captured between 1.1 and 13.54 rkm. The other 3 females (201 to 393 mm) were captured between 7.79 and 12.64 rkm. Fourteen ripe male flannelmouth sucker (340 to 535 mm) were captured; all were captured at 3 rkm, except 1 at 2.3 rkm. Two ripe female flannelmouth sucker (465 and 535 mm) were captured at 3 and 8.7 rkm. Five hundred thirty-three ripe male bluehead sucker (162 to 326 mm) were captured between 1.1 and 12.13 rkm. Sixty-four ripe female bluehead sucker (182 to 315 mm) were captured between 1.14 and 12.13 rkm. Although spawning (ripe) aggregations of bluehead sucker were captured throughout the river, 46% of the ripe fish were captured in Boulders reach, 39% in Coyote reach, and 15% in Salt reach. This closely matched the proportions of all bluehead sucker captured (both ripe and non-ripe) in the river (Boulders = 42%, Coyote = 38%, Salt = 20%). One gravid catfish (475 mm) was captured at 10.33 rkm. Finally, 206 ripe speckled dace (115 males and 91 females) and 110 ripe fathead minnow (23 males, 87 females) were seen in Boulders reach (because of time constraints these fish were not always checked for ripeness in Boulders, and certainly were not checked in Coyote or Salt reaches).

During April, 57 of 244 HBC ≥ 200 mm captured were ripe (i.e., 23.4% of the captured adult population in April was ripe). During May, 94 of 402 HBC ≥ 200 mm captured were ripe (i.e., 23.4% of the captured adult population was ripe). Combining both trips, 18% (27 fish) of ripe HBC ≥ 200 mm were captured in Boulders reach, with 24% (36 fish) in Coyote reach, and 58% (88 fish) in Salt reach; suggesting that spawning activities of HBC take place progressively further upriver in the LCR. This is also reflected in the fact that more adult HBC ≥ 200 mm (whether ripe or non ripe) are captured progressively upriver, with 14% (89 fish) in Boulders reach, 16% (101 fish) in Coyote reach and 42% (456 fish) in Salt reach.

Predation

The stomach contents of 14 black bullhead were examined during both trips. A 195 mm bullhead had a 62 mm bluehead sucker in its stomach and 2 other bullhead (190 and 159 mm) had fish bones or other body parts in their stomachs. The remainder had detritus (6 fish), insects (1 fish) or nothing (4 fish) in their stomachs. Five channel catfish were examined for stomach contents. One catfish (475 mm) was a gravid female and had 2 unidentifiable fish in her stomach. Another one had detritus in its stomach. One brown trout (405 mm) was examined and had 2 vertebral columns from fish in its stomach. No direct predation on HBC was detected, but 16 HBC (172 to 442 mm) and 5 bluehead sucker (185 to 265 mm) had presumed catfish bite marks on them.

Parasites

Percent occurrence of the external parasite (*Lernaea cyprinacea*) on HBC (57 to 420 mm) in April was moderate, with 150 fish (8.7% of total HBC captures) observed carrying from 1 to 10 parasites (mean = 1.6 parasites/infested fish). In addition, 1 flannelmouth sucker (195 mm) and 1 speckled dace (71 mm) were observed carrying the parasite. During May, 235 HBC (74 to 421 mm) were parasitized (7.5 % of total HBC captures), each carrying 1 to 7 *Lernaea* (mean = 1.4 parasites/infested fish). In addition, 6 speckled dace (50 to 78 mm), 2 flannelmouth sucker (217 mm) and 2 fathead minnow (63 and 81 mm) were each parasitized by a single *Lernaea*. Occurrence of the Asian fish tapeworm (*Bothriocephalus acheilognathi*) was not monitored during these trips.

Population Abundance Estimation

The following criteria were used to define the sampled population during the spring mark-recapture effort. During April, 385 unique HBC ≥ 150 mm were marked [*M*]. During May, 613 unique HBC ≥ 150 mm were captured [*C*], of which 139 unique HBC ≥ 150 mm were recaptures [*R*]. The smallest HBC recaptured had a total length of 152 mm, and the largest recaptured HBC was 406 mm. We defined our sampled population to include all HBC ≥ 150 mm.

Length frequency distributions of HBC ≥ 150 mm reflected no obvious violations to the assumption of population closure. Figures 10 and 11 illustrate nearly identical length frequency distributions between marked [M] and captured [C] fish, and closely aligned length frequency distributions between marked [M] and recaptured [R} fish. Moreover, the two-tailed K-S tests reflected no significant differences between the length frequency distribution of marked [*M*] HBC and captured [*C*] HBC ($n_1 = 385$, $n_2 = 613$, $Z = 1.027$, $p = 0.243$), nor between marked [*M*] HBC and recaptured [*R*] HBC ($n_1 = 385$, $n_2 = 139$, $Z = 0.967$, $p = 0.307$). The typical conclusion drawn from these non-significant test results is that there is no size selective sampling during marking or the recapture events (Bernard and Hansen 1992). However, there was significant difference ($\chi^2 = 22.51$, df = 5, $p < 0.001$) in the mark rates of HBC among different length strata (Table 5). When mark rate differs as a function of length, it is appropriate to stratify the data into one or more length categories to obtain an unbiased estimate of the abundance (Seber 2002, Bernard and Hansen 1992).

In addition, we tested for significant differences in mark rate among the three geographic strata. We found significant difference ($\chi^2 = 187.71$, df = 2, $p < 0.0001$) in the mark rate among the Salt, Coyote and Boulders reaches (Table 6).

Upon further testing, we found that there was a highly significant difference between all reach combinations ($p < 0.00001$), except between Boulder and Coyote reaches, which had only a marginally significant difference between their mark rates ($\chi^2 = 4.0$, df = 1, p = 0.0453). Optimally, this would suggest to stratify the abundance estimate by length separately within the Salt, Coyote, and Boulders reaches, and to sum the three estimates to obtain a final estimate. However, in order to be 95% confident that the bias of the abundance estimate is negligible, a minimum of 7 recaptures is considered necessary (Seber 2002). As a result of only 6 recaptures in the Coyote reach, stratifying this reach by length was impractical. The remaining option was to pool the data from Coyote and Boulders reaches (with 18 recaptures total), and perform a length stratified estimate using this pooled data. To this was summed a length stratified estimate from the Salt reach (with 121 recaptures).

The optimal length stratification is found by choosing length boundaries in a contingency table of unmarked and marked fish (e.g., Table 5) that maximizes the homogeneity in mark rate among length groups (Seber 2002, Bernard and Hansen 1992). This was performed for Salt reach and for the pooled Coyote and Boulders reaches. The optimal length stratification for Salt reach occurred at 290 mm ($\chi^2 = 8.33$). This means that at Salt reach independent estimates were produced for HBC from 150 to 290 mm and for HBC > 290 mm. The optimal length stratification for the pooled Coyote and Boulders reaches occurred at 200 mm ($\chi^2 = 1.62$). This means that at the pooled Coyote and Boulders reaches independent estimates were produced for HBC from 150 to 200 mm and for HBC > 200 mm (Table 7). The resulting and preferred summed estimate (of all three reaches) for HBC ≥ 150 mm is 2,261 fish (SE = 285). Table 8 and Figure 12 show this estimate as compared against historical estimates.

To calculate the abundance of HBC ≥ 200 mm, the length stratified Chapman Petersen estimate of HBC from 150 to 290 mm in Salt reach (N^* = 653 fish) was multiplied by the proportion (0.55) within this size class of fish ≥ 200 in Salt reach using Equation 3. To this was summed the length stratified estimate of HBC > 290 mm from Salt reach (N^* = 164 fish). Additionally, the length stratified estimate for HBC > 200 mm from the pooled Coyote and Boulders reaches was added, modifying it slightly to be inclusive of HBC ≥ 200 mm (i.e., 1 more marked fish and 1 more captured fish were added to the calculation, giving an estimate of 817 fish ≥ 200 mm rather than 796 fish > 200 mm). This process provided a preferred summed estimate of HBC ≥ 200 mm from all three reaches of 1,339 fish (SE = 249; Table 9). Table 10 and Figure 13 show this estimate as compared against the spring estimates for the past five years.

Since mark-recapture efforts were reinitiated again in fall 2000, insufficient recaptures of BHS have prevented generating a population abundance estimate for this species. However, during spring of 2006, 5 BHS were recaptured. Again, in order to be 95% confident that the bias of the abundance estimate is negligible, a minimum of 7 recaptures is considered necessary (Seber 2002). As a result, the estimate provided has lower precision than is desired. However, since recaptures for this species are so rare, and since virtually nothing to date has been generated on the population abundance of BHS in the LCR, it was decided to provide an estimate, despite the recognized shortcomings. During April, 105 unique BHS ≥ 150 mm were marked [*M*]. During May, 695 unique BHS ≥ 150 mm were captured [*C*], and 5 unique BHS ≥ 150 mm were recaptured [*R*]. The smallest BHS recaptured had a total length of 184 mm, and the largest recaptured BHS was 282 mm in TL. We defined our sampled population to include all BHS ≥ 184 mm. Using the two-tailed K-S tests, the cumulative length distribution of marked [*M*] BHS was not significantly different from captured [*C*] BHS ($n_1 = 105$, $n_2 = 695$, $Z = 0.995$, $p = 0.275$). Likewise, the cumulative length distribution of marked [*M*] BHS was not significantly different from recaptured [*R*] BHS ($n_1 = 105$, $n_2 = 5$, $Z = 0.583$, $p = 0.886$). There was no significant difference ($\chi^2 = 0.91$, df = 3, $p < 0.822$) in the mark rates of BHS among different length strata. It was not possible to test for differences in the mark rate between the three geographic reaches since no recaptures occurred in the Salt reach. An non-stratified Chapman Peterson abundance estimate of 12,295 (SE = 4,495) BHS ≥ 184 mm was obtained (Table 11). Because there were no recaptures in the Salt reach, a truncated estimate is also given for the combined Coyote and Boulders reaches and for the Boulders reach alone (Table 11). In addition, unpublished data from GCMRC was used to generate comparable historical estimates for the abundance of BHS ≥ 182 mm (i.e. smallest recapture size) during April/May of 1993 (Table 11). As with the 2006 estimates, recaptures were low (i.e., 7 recaptures in all), and the data was truncated to provide estimates for specific appropriate reaches.

FALL RESULTS (CONFLUENCE TO LOWER ATOMIZER)

Physical Parameters

During the September trip, the LCR was nearing base flow levels from a preceding series of flood events that had begun on 30 July and continued through just prior to the sampling trip (Figure 14). Several of the mean daily peaks during these flood events had been > 1,500 cfs and two had been > 2,300 cfs (Figure 14), representing a fairly substantial monsoonal season for the LCR basin. Turbidity was at a high of 29,136 NTUs on the second day of the trip (20 September), and thereafter declined to a low of 931 NTUs on the last day of fishing (28 September; Figure 15). Daily afternoon water temperatures ranged between 17.9 and 20.4 ^{o}C (mean = 19.1 ^{o}C).

During the October trip, the LCR was again nearing base flows after experiencing another episode of flooding events that began on 5 October, and reached a peak mean daily flow of >2,500 cfs on 6 October at the Cameron Gage station (Figure 14). The flooding continued to dissipate as the trip continued. A high of 59,296 NTUs was taken on the first day of the trip. Thereafter turbidities declined to 8,624 NTUs on the last day of fishing on 28

October (Figure 15). Daily afternoon water temperatures ranged from 13.1 to 17.5 ^{o}C (mean = 15.8 ^{o}C).

Effort and Catch

A total of 1,080 hoop net sets were completed during the September and October trips yielding 25,132 hours of fishing effort. Total CPE for HBC in September was 0.028 fish/net-hour, and in October was 0.029 fish/net-hour, representing low catch rates (Table 12). The distribution of effort was similar among the three reaches. Fishing effort during these trips produced a catch of 1,033 fish (Table 13). The dominant species in the catch were HBC (717 fish; 69%) and speckled dace (102 fish; 10%). Black bullhead comprised the dominant nonnative species (94 fish; 9%).

Species Composition

Observed species composition during both the September and October trips were similar with only minor differences (Figure 16). HBC comprised the largest proportion of fish caught on both trips (71% and 69%). Speckled dace increased in proportion from 8% of the catch in September to 11% of the catch in October. The proportion of carp increased from 4% in September to 6% in October. Nonnative species in order of decreasing catch included 94 black bullhead, 53 carp, 12 fathead minnow and 4 channel catfish. No green sunfish, red shiner, plains killifish, or rainbow trout were captured during the fall 2006 trips. Nonnative species captured in hoop nets during September and October comprised 16.3% and 15.3% of the catch, respectively.

Length Frequency Distributions and Catch

Nearly equal numbers of HBC were captured during the September (350 fish) and October (367 fish) trips (Table 13, Figure 17). Small numbers of HBC (<100 mm) were detected during both trips (34 fish in September and 29 in October; 9% of all HBC captured during both trips). These low numbers suggest that much of the 2006 age-0 cohort may have been lost to the mainstem because of the repeated flood events (i.e., there was no large spike of age-0 HBC as is sometimes seen during fall sampling). Most HBC on both trips fell into the 100 to 299 mm size class (292 fish in September, 324 fish in October, 86% of all HBC captured on both trips); with modes on both trips falling near ~150 mm, and very little distinction between cohorts. The remainder of the fish were comprised of HBC ≥ 300 mm (24 fish in September, 14 fish in October, 5% of all HBC captured on both trips). Cumulative length frequency distributions for HBC (Figure 18) show higher proportions of fish < 100 mm at Boulders and Coyote reaches on both trips compared to Salt reach (49%, 33% and 18% of all HBC < 100 mm captured, respectively). This appears to be a typical distributional pattern for age-0 HBC in LCR (i.e., more age-0 HBC are usually captured in the Boulders and Coyote reaches than in the Salt reach).

Flannelmouth sucker length frequency distributions show that few fish were captured (8 fish in September, 18 fish in October), and that these few fish fell into a mixed assortment of sizes (Figure 19). The majority of flannelmouth sucker (73%, 19 fish) were captured in Boulders reach, while 15% (4 fish) and 12% (3 fish) were captured in the Coyote and Salt reaches, respectively (Table 13). Only 2 presumed age-0 flannelmouth sucker (<125 mm) were captured during both trips combined.

Bluehead sucker length frequency distributions show that all but 1 of the captured fish fell between 198 and 305 mm (Figure 20); the exception being 1 age-0 fish (89 mm) captured during October in Boulders reach. The majority of bluehead sucker were captured in Boulders reach (68%, 17 fish), with 8% (2 fish), and 24% (6 fish) captured in Coyote and Salt reaches, respectively (Table 13). The lack of bluehead sucker captures during the fall (Figure 20) stands in stark contrast to the high catches in the spring (Figure 8).

Length frequency distributions for black bullhead, channel catfish and carp (Figure 21) show that there were age-0 fish for each of these species present, indicating that spawning of these species had occurred in the lower LCR, or that immigration from upriver sources during the monsoonal flood events had occurred. Black bullhead length frequency distribution shows a normal distribution with a mode at ~200 mm (Figure 21). Ninety-four black bullhead were captured during the fall 2006 trips, representing the highest CPE for bullhead (0.0037 fish/net-hr) since mark-recapture efforts were reinitiated in fall 2000; suggesting that either the abundance of bullhead increased this year via spawning in the lower LCR, or that the 2006 monsoonal floods flushed fish into the lower LCR from the upper watershed as hypothesized by Stone et al (2006). The length frequency distribution chart for carp shows representative fish from assorted size classes, and the length frequency distribution chart for channel catfish shows only 4 age-0 fish (Figure 21). Probably under-represented in these charts are the presence of adult channel catfish and carp, that have low catch rates in hoop nets.

Sexual Condition

During the September trip, 10 ripe HBC were captured. All of them were male (163 to 346 mm) and were captured between 0.54 and 9.10 rkm. Four ripe bluehead sucker were captured. All were male (198 to 230 mm) and were captured between 1.62 and 3.74 rkm. Additionally, 1 ripe male flannelmouth sucker (440 mm) was captured at 0.3 rkm.

During the October trip, 1 ripe male HBC (205 mm) was captured at 2.48 rkm. One ripe male bluehead sucker (238 mm) was captured at 0.1 rkm. Finally, 1 ripe male flannelmouth sucker (364 mm) was captured at 1.57 rkm.

Predation

Stomach contents from 79 black bullhead were examined during both trips. One bullhead (219 mm) had a speckled dace (68 mm) in its stomach, and 4 other bullhead (222, 252, 176, and 200 mm) had the remains of unidentified fish in their stomachs; with the last 2 containing prey of 47 and 93 mm, respectively. Six bullhead had carp scales in their stomachs, 8 bullhead had invertebrates in their stomachs, and 17 had detritus in their stomachs. Presumed catfish bites were observed on 6 HBC (212 to 300 mm) and 1 bluehead sucker (251 mm) during the September trip, and on 9 HBC (195 to 300 mm) and 1 bluehead sucker (234 mm) during the October trip; 94% of these observations came from the Salt reach.

Parasites

Percent occurrence of the external anchorworm, *Lernaea cyprinacea*, on HBC in September was low, with 20 fish (113 to 400 mm; 5.7% of total HBC captures) observed carrying 1 to 3 parasites (mean = 0.71 parasites/infested fish). Two speckled dace each carried 1 *Lernaea* per fish. During October, 12 HBC were seen with anchorworm (106 to 400 mm; 3.3 % of total HBC captures), each carrying 1 to 4 parasites per fish (mean = 0.8 parasites/infested fish).

Population Abundance Estimation

The following criteria were used to define the sampled population during the fall mark-recapture effort. During September, 230 unique HBC $\geq$ 150 mm were marked [*M*]. During October, 239 unique HBC $\geq$ 150 mm were captured [*C*], of which 30 unique HBC $\geq$ 150 mm were recaptures [*R*]. The smallest HBC recaptured was 158 mm, and the largest HBC recaptured was 304 mm.

Figures 22 and 23, show some discrepancies in the length frequency distributions of marked, captured and recaptured fish. Two-tailed K-S tests revealed that the length distribution of marked [*M*] HBC was significantly different from captured [*C*] HBC ($n_1 = 230$, $n_2 = 239$, $Z = 1.787$, $p = 0.003$). However, the length distribution of marked [*M*] HBC was not significantly different from recaptured [*R*] HBC ($n_1 = 230$, $n_3 = 30$, $Z = 1.277$, $p = 0.077$). It was also found that there was no significant difference ($\chi^2 = 1.88$, df = 5, $p = 0.865$) in the mark rates of HBC within different length strata (Table 14). Since the population of marked fish was found to be significantly different from the population of captured fish, it was considered necessary to stratify our abundance estimate based on length (Bernard and Hansen 1992, Seber 2002).

In addition, we tested for significant differences in mark rate among the three geographic strata, but detected no significant difference ($\chi^2 = 5.48$, df = 2, $p = 0.065$) in the mark rate among the three sampling reaches (Table 15). This test indicated that the abundance estimate need not be stratified by location (i.e., Salt, Coyote and Boulders reaches).

Based on the above tests, it was concluded that stratification by length, but not by geographic reach, was necessary for unbiased estimation of abundance. This procedure was performed, and the optimal length stratification occurred at 210 mm (χ^2 = 8.55). This means that independent estimates were produced for HBC from 150 to 210 mm and for HBC > 210 mm (Table 16). The resulting summed length stratified Chapman Petersen abundance estimate for HBC ≥ 150 in the lower 13.57 rkm of the LCR was 1,925 fish (SE = 361, Table 16). Table 17 and Figure 24 show this estimate as compared against the historical estimates obtained by Douglas and Marsh (1996) for HBC ≥ 150 mm during these months.

Since the Recovery Goals for HBC (USFWS 2002) focus on abundance estimates of fish ≥ 200 mm, an estimate is presented relating to their abundance. The above stratified Chapman Petersen estimate for HBC from 150 to 210 mm was multiplied by the proportion (0.15) of HBC within that size class ≥ 200 mm using Equation 3. To this was summed with the length stratified abundance estimate of HBC > 210 mm. The resulting summed abundance estimate of HBC ≥ 200 was 1,347 fish (SE = 342). Table 18 and Figure 25 show this against historical estimates since 2001.

CHUTE FALLS RESULTS (ABOVE LOWER ATOMIZER TO 18.1 RKM)

Physical Parameters

The LCR was running at base flow during both the May and June monitoring trips (Figures 2 and 14). Turbidity was low during the May trip (range = 2.1 to 3.5 NTUs, mean = 2.9 NTUs) and during the June trip (range = 1.2 to 1.5 NTUs, mean = 1.4 NTUs). Daily afternoon temperatures during the May trip ranged from 18.5 to 21.6 ^{o}C (mean = 20.4 ^{o}C) and during the June trip ranged from 20.6 to 22.1 ^{o}C (mean = 21.1 ^{o}C). Our measurement of mean dissolved CO_2 was 220 (SE = 5.0) mg/l during the May trip and 229 (SE = 4.91) mg/l during the June trip.

Effort and Catch

A total of 299 hoop net sets were completed during the May and June trips yielding 6,993 hours of fishing effort. Total CPE for HBC in May was 0.145 fish/net-hour and in June was 0.211 fish/net-hour; representing high catch rates (Table 19). The distribution of effort was unequal between the upper reach (above Chute Falls) and the lower reach (between Lower Atomizer Falls and the base of Chute Falls), because the upper reach was inclusive of roughly 4 times the distance (upper = 2.0 rkm, lower = 0.53 rkm). Fishing effort during these trips produced a catch of 13,954 fish (Table 20). The dominant species in the catch were speckled dace (12,263 fish; 88% of total fish captures) and HBC (1,430 fish; 10% of total fish captures). Fathead minnow comprised the dominant nonnative species (130 fish; <1% of total fish captures).

Species Composition

Observed species composition during both the May and June trips were similar with only minor differences. Speckled dace comprised the largest proportion of fish caught on both trips (90% and 89%). HBC comprised 8% of fish captures on the May trip and 10% on the June trip. However, a large shift in species composition occurs in comparing the fish communities above and below the demarcation at Chute Falls, or between the upper and lower reaches (Figure 26). Speckled dace was clearly the dominant fish species above Chute Falls (94% of the catch, 12,038 fish), but comprised only 22% (225 fish) of the catch below Chute Falls. In stark contrast, HBC comprised only 4% (498 fish) of the catch above Chute Falls, but 74% (932 fish) of the catch below Chute Falls. HBC captures noticeably dwindled upriver of 17.04 km, despite the deployment of 36 net sets further upriver to 18.01 km, while speckled dace increased at progressively further upriver sampling locations (Figure 27). Only 1 flannelmouth sucker was captured in the lower reach. Nonnative species in order of decreasing catch were 130 fathead minnow, 93 carp, 36 black bullhead, and 1 plains killifish. No channel catfish, green sunfish, red shiner, brown trout or rainbow trout were captured. Nonnative species captured in the May and June trips comprised only 2.6% and 1.2% of the catch, respectively.

Length Frequency Distributions and Catch

Length frequency distributions of HBC show some differences between fish captured in the lower and the upper reaches during the May and June trips (Figure 28). More HBC were captured in the lower reach below Chute Falls (932 total HBC) than were in the upper reach above Chute Falls (498 total HBC; Table 20). The majority of HBC fell into the 100 to 199 mm size category (upper reach = 64%, 318 fish; lower reach = 57%, 528 fish), while smaller proportions fell into the 200 to 299 mm size category (upper reach = 34%, 170 fish; lower reach = 36%, 338 fish), or into the ≥ 300 mm size class (upper reach = 2%, 10 fish; lower reach = 7%, 65 fish). Only 1 presumed age-0 HBC (60 mm) was captured in the lower reach, during the June trip. The largest HBC captured in the upper reach was 341 mm, while the largest HBC captured in the lower reach was 395 mm.

Length frequency distributions of speckled dace above and below Chute Falls are shown in Figure 29, however, little can be said, except that the charts reflect the much higher catches of speckled dace above Chute Falls, and measured dace ranged in length between 23 and 130 mm. Since not all speckled dace were measured above Chute Falls (only 24% were measured), a comparison of mean size between the upper and lower reaches was considered invalid (i.e., researchers may have been inadvertently measuring larger speckled dace above Chute Falls since random selections for measurements were not performed).

Only 1 flannelmouth sucker (448 mm) was captured on the June trip; this capture occurred in the lower reach below Chute Falls. No bluehead sucker were captured on either trips.

Length frequency distributions for fathead minnow, carp and black bullhead from the upper and lower reaches show a similar pattern to speckled dace in that catches for all of these species were noticeably higher in the upper reach above Chute Falls (Figure 29). Noticeable was the complete absence of carp ≤ 200 mm from the lower reach in comparison to the upper reach that displayed two distinct cohorts (presumably age-0 fish, and age-1 fish between 130 and 210 mm).

Sexual Condition

Humpback chub were likely spawning in both reaches. During the May trip below Chute Falls, 25 ripe male HBC (210 to 307 mm) were captured. Another 93 males and 85 females displayed breeding coloration. One of the males was tuberculate as well. During the May trip above Chute Falls, 23 ripe males (150 to 306 mm) were captured. Another 27 males and 39 females displayed breeding coloration. No ripe (extruding gametes) female HBC were observed during the May trip. During the June trip below Chute Falls, male HBC were not examined for ripeness, but 1 ripe female HBC (352 mm) was captured. Another 86 males and 67 females displayed breeding coloration. Two of these males and 1 of these females were also tuberculate. During the June trip above Chute Falls, 16 ripe male HBC (180-270 mm) were captured. Another 39 males and 28 females displayed breeding coloration. No fish from another species were identified as ripe or displaying any other spawning characteristics during either the May or June trips.

Predation

Fish remains were detected in the stomach contents of 3 black bullhead (253, 245 and 204 mm), all were captured above Chute Falls. The 253 and 245 mm black bullhead each had 2 speckled dace in their stomach, and the 204 mm bullhead had 1 speckled dace and 1 fathead minnow it its stomach.

Parasites

The external anchorworm, *Lernaea cyprinacea*, was only detected on 5 HBC (124 to 210 mm) below Chute Falls and 2 HBC (120 to 122 mm) above Chute Falls (0.5% of all HBC captures); each had 1 to 3 parasites/fish. The parasite was not found on any of the other fish species.

Population Abundance Estimation

The following criteria were used to define the sampled population during the Chute Falls area mark-recapture effort. Since the translocated population of HBC above Chute Falls is of particular interest, and since this population is assumed to be a one way closed population, our approach was to provide abundance estimates of HBC from the lower and upper reaches separately, and then to sum the two. In the lower reach during May, 320 unique HBC ≥ 100 mm were marked [*M*], and during June 419 unique HBC ≥ 100 mm were captured [*C*], of which 208 of these fish were recaptures [*R*]. The smallest HBC recaptured was 124 mm, and the largest HBC recaptured was 395 mm. In the upper reach during May, 220 unique HBC ≥ 100 mm were marked [*M*], and during June, 197 unique HBC ≥ 100 mm were captured [*C*], of which 105 of these fish were recaptures [*R*]. The smallest HBC recaptured was 122 mm, and the largest HBC recaptured was 315 mm. Since the size of the smallest recaptures both above and below Chute Falls was near 125 mm, this is where we defined the lower size limits for our abundance estimates (Seber 2002).

Figure 30 displays some minor discrepancies in the length frequency distributions between marked and captured fish, and between marked and recaptured fish, in both the lower and upper reaches. In the lower reach, two-tailed K-S tests, indicated that the length distribution of marked [*M*] HBC was significantly different from captured [*C*] HBC ($n_1 = 320$, $n_2 = 419$, $Z = 1.803$, $p = 0.003$), as was the length distribution of marked [*M*] HBC and recaptured [*R*] HBC ($n_1 = 320$, $n_3 = 208$, $Z = 2.183$, $p < 0.001$). In the upper reach, two-tailed K-S tests indicated that the length distribution of marked [*M*] HBC was significantly different from captured [*C*] HBC ($n_1 = 220$, $n_2 = 197$, $Z = 2.163$, $p < 0.001$), as was the length distribution of marked [*M*] HBC and recaptured [*R*] HBC ($n_1 = 220$, $n_3 = 105$, $Z = 2.394$, $p < 0.001$). It was also found that there was significant difference in the mark rates of HBC within different length strata in the lower reach ($\chi^2 = 52.54$, df = 5, $p < 0.001$), but not in the upper reach ($\chi^2 = 2.76$, df = 4, $p = 0.598$; Table 21). Since the K-s tests revealed that the length frequency distribution of marked fish was significantly different from captured fish in both the lower and upper reaches, it was considered necessary to length stratify our abundance estimates for both reaches (Seber 2002, Bernard and Hansen 1992).

The resulting length stratified Chapman Petersen abundance estimate for HBC ≥ 125 in the lower reach below Chute Falls (13.57 to 14.1 rkm) in the LCR was 707 fish (SE = 42). The resulting length stratified Chapman Petersen abundance estimate for HBC ≥ 125 in the upper reach above Chute Falls (14.1 to 18.1 rkm) in the LCR was 440 fish (SE = 35; Table 22). For both the lower and upper reaches combined, we obtained a summed abundance estimate of 1,147 fish (SE = 54; Table 22).

In order to provide abundance estimates that conform to the spring and fall mark-recapture efforts presented above, we also provide abundance estimates for HBC ≥ 150 mm from both the lower and upper reaches. For the lower reach, the length stratified Chapman Petersen estimate of HBC ≥ 141 mm ($N^* = 428$) was multiplied by the proportion (0.77) of fish ≥ 150 mm using Equation 3. This resulted in an abundance estimate of 328 fish (SE = 25) ≥ 150 mm (Table 23). For the upper reach, the length stratified Chapman Petersen estimate of HBC from 100 to 150 mm was multiplied by the proportion of fish that equaled 150 mm using Equation 3. This number (19 fish) was summed with the length stratified estimate of HBC >150 mm to give an abundance estimate of 258 fish (SE = 12)

≥150 mm. However in this instance, it was considered to be the most parsimonious to truncate the data for HBC ≥ 150 mm. This was performed giving the nearly identical and **preferred** estimate of 255 fish (SE = 11). For both the lower and upper reaches combined, we obtained a summed abundance estimate of 583 fish (SE = 27; Table 23).

Since the Recovery Goals for HBC (USFWS 2002) focus on abundance estimates of fish ≥ 200 mm, estimates are presented relating to their abundance. In the lower reach, the stratified Chapman Petersen estimate for fish ≥ 141 mm (N* = 428 fish) was multiplied by the proportion (0.48) of HBC ≥ 200 mm, giving a resulting abundance estimate of 206 fish (SE = 18; Table 24). In the upper reach the truncated Chapman Petersen estimate for HBC ≥ 150 mm (N* = 255 fish) was multiplied by the proportion (0.49) of HBC ≥ 200 mm using Equation 3, giving a resulting abundance estimate of 125 fish (SE = 15; Table 23). For both the lower and upper reaches combined, we obtained a summed abundance estimate of 331 fish (SE = 23; Table 24).

DISCUSSION AND CONCLUSIONS

Spring HBC Abundance Estimate

For the spring of 2006, the abundance estimate of HBC ≥ 150 mm was derived by summing the length stratified abundance estimate from Salt Reach to the length stratified abundance estimate from the pooled Coyote and Boulders reaches. Length frequency analyses did not provide an indication that the assumption of population closure was violated (e.g., that there was migratory activity occurring in the LCR between the mark and recapture events). The K-S tests showed no significant differences between the length frequency distributions of marked and captured fish or between the marked and recaptured fish. However, there was a significant difference in the mark rates among 50 mm size classes of fish. In addition, significant difference was found in the mark rates among the three geographical reaches (i.e., Boulders, Coyote and Salt). Because of these test results, and other complications explained in the results section (e.g., too few recaptures in the Coyote reach) we chose to stratify an abundance estimate by length in the Salt reach, and to sum this with a length stratified estimated from the pooled Boulders and Coyote reaches. This provided a preferred abundance estimate of 2,261 (SE = 285) HBC ≥ 150 mm in the lower 13.57 rkm of the LCR during the spring of 2006.

This population estimate supplies additional evidence that the LCR population of HBC has undergone a decline since the early 1990s. All six spring point abundance estimates for HBC ≥ 150 mm from the years 2001 through 2006 have been less than those provided by Douglas and Marsh (1996) during spring 1992 (although not all have been significantly less). Since 2001, however, spring population abundance estimates for HBC ≥ 150 mm have remained relatively constant, suggesting that the population may have reached a degree of equilibrium. Except for 2003, the spring abundance estimates of HBC ≥ 150 since 2001 have remained relatively stable (mean = 2,540, SE = 193). As discussed in previous reports (e.g., Van Haverbeke 2006) the short term abundance increase witnessed in spring of 2003 may have been caused by high survivorship from the 2000 or 2001 cohorts.

Also of interest are the abundance estimates of HBC ≥ 200 mm. In addition of a criterion for no significant decline, the Recovery Goals for HBC call for a minimum viable population of 2,100 HBC ≥ 200 mm in Grand Canyon (USFWS 2002). The spring 2006 estimate for HBC ≥ 200 mm in the LCR falls at 1,339 (SE = 249). It is noteworthy that all spring abundance estimates provided from 2001 to 2006 fall below 2,100 fish, but that the abundance estimates have remained relatively stable since 2001 (mean = 1,598, SE = 105). It is hypothesized that this apparent “stabilization” is related to some aspect of the carrying capacity within the LCR (e.g., recruitment capacity, overwintering capacity for juveniles and subadults, spawning capacity). In other words, we concur with a hypothesis that the initial population decline was caused by prohibiting mainstem factors (e.g., poor survivorship of age-0 HBC in the mainstem, followed by a precipitous decline in abundance). The apparent stabilization since 2001 is hypothesized to be related to the overall HBC population reaching an equilibration with the capacity of LCR to produce fish that survive to adulthood. Although this population “stabilization” could be viewed as a promising sign, it should be made clear that a small population such as the HBC in a highly stochastic system such as the LCR is still likely at high risk of extirpation.

Finally, as mentioned in the introduction section, our annual closed LCR estimates by themselves are not intended to provide an estimate of the overall LCR population because some portion of HBC will be in the mainstem Colorado River during our activities and will not be captured in the estimate. Our annual data are incorporated into open population models (i.e., Jolly-Seber in Program Mark, and ASMR) in order to estimate the entire LCR population.

Spring HBC Sexual Condition

As in previous years, there was a low percentage of ripe female HBC compared to ripe male HBC during the spring sampling of 2006 (i.e., spring 2006 = 10 ripe females and 177 ripe males; spring 2005 = 3 /42; spring 2004 = 6/113; spring 2003 = 4/115; spring 2002 = 14/123, spring 2001 = 6/84). Gorman and Stone (1999) found a similar ratio during the spawning seasons of 1993 to 1995 (i.e., 16/93). Overall this produces an observed spring spawning population consisting of 6% ripe females and 94% ripe males. Hoop net catch data over the years in the LCR has consistently shown that one or two ripe females are typically accompanied by numerous ripe males (GCMRC, unpublished data). Gorman and Stone (1999) also found that ripe females appeared to move into aggregations of ripe males to spawn, and found that while males have a protracted time span for being in a ripe condition; females are ripe for a shorter time span.

The Recovery Goals make the assumption that there is a 1:1 effective sex ratio in terms of contributors to the next generation (USFWS 2002). Even though a 1:1 sex ratio may exist in the wild for HBC (Valdez and Ryel 1995), this may not necessarily equate into a 1:1 effective sex ratio during spawning activities. As Soulé (1980) stated, “breeding structure is absolutely critical.” The data suggest that the breeding structure for HBC may be more complex than simply assuming a 1:1 effective sex ratio. This is important, since the effective sex ratio has an impact on the estimation of the effective population size (N_e), and indeed is part of the basic equation in estimating N_e (e.g., Lande and Barrowclough 1987).

Spring Bluehead Sucker Abundance Estimates

The obtainment of an abundance estimate for BHS for spring of 1993 and 2006 represent the first known effort to obtain abundance estimates for this species in the LCR. Less than desirable numbers of recaptures during both years resulted in the estimates lacking precision; however, since BHS recaptures are so rare it was considered of value to present the results. Although confidence intervals are very wide, a few points are discussed. First, it can be stated that there were likely several thousand adult BHS inhabiting the LCR during the spring spawning events of 1993 and 2006. Confidence intervals aside, it would appear that there may have been more than twice as many BHS ≥ 180 mm inhabiting the LCR during the spring spawning event of 2006 than there were in spring of 1993 (Table 11). Second, it would appear that while the Salt and Coyote reaches may have had roughly 1.8 times as many BHS in 2006 compared to 1993, Boulders reach may have had about 3 times as many BHS in spring 2006 compared to spring 1993. These results, although tenuous, might support two hypotheses. First, the apparent overall increase in the abundance of BHS may be the result of the recent warmer temperatures experienced in the mainstem Colorado River, combined with the mechanical removal of trout in the mainstem. AZGFD personnel have also witnessed dramatic increases in catch rates of bluehead sucker in the mainstem, particularly between river miles 100 to 170, but also in the LCR inflow area, and at present believe this is the result of the recent warming of mainstem waters (S. Rogers, pers. com.). These increases may reflect positive changes (i.e., increased recruitment). Second, if HBC are becoming more of a resident LCR population with a decline in the migrating portion of the population, as Douglas and Marsh (1996) hypothesized, BHS may be filling a carrying capacity void, particularly in the Boulders reach.

Fall HBC Abundance Estimate

A length stratified abundance Chapman Peterson abundance estimates is provided for this year's fall abundance estimate of HBC ≥ 150 mm. There was a significant difference in the length frequency distribution between marked and captured HBC ≥ 150 mm, but not between marked and recaptured fish. There were no significant differences in the mark rates among the length strata, or among the geographic reaches. These tests suggested that some violation of the closure assumption may have occurred during the fall mark-recapture events. This year's fall estimate of 1,925 (SE = 361) HBC ≥ 150 mm is higher (although not significantly higher) than last year's estimate of 1,523 fish (SE = 113).

To generate the fall 2006 estimate of 1,347 (SE = 342) HBC ≥ 200 mm, the length stratified Chapman Petersen estimate for HBC from 150 to 210 mm was multiplied by the proportion of HBC from 200 to 210 mm. To this was summed the length stratified Chapman Petersen abundance estimate of HBC > 200 mm. This number (1,347 HBC ≥ 299 mm) represents the highest fall abundance estimate obtained for this size class of HBC since the fall mark-recapture efforts were initiated in 2000, and is significantly higher than either the fall 2001 or 2005 estimates. Notably, the fall 2006 estimate of 1,347 HBC ≥ 200 mm is nearly identical to the spring 2006 estimate of HBC ≥ 200 mm (1,339 fish). This is of some interest since without exception the fall estimates for HBC ≥ 200 mm obtained from 2001 to 2005 (Table 17) have been considerably lower than the spring estimates of HBC ≥ 200 mm (Table 10). This has generally been explained because a portion of HBC migrate out of the LCR after the spring spawning event (Gorman and Stone 1999). This year may represent an anomaly, although currently we can offer no explanation (i.e., it could represent an increasing abundance of HBC ≥ 200 mm, but just as equally could mean that the ordinary portion of adult HBC did not emigrate from the LCR after the spring spawning event as is usual, possibly related to the summer monsoonal activity).

Both the fall and spring abundance estimates also provide trend data indicating that the numbers of these larger fish still remain lower than perhaps would be desired. The fall abundances of HBC ≥ 200 mm since 2001 have remained low (i.e., < 1,000 fish, with the exception of this year), providing evidence that the numbers of these fish residing year round in the LCR is low, and that carrying capacity in the LCR alone for these larger fish may be lower than is desired for recovery purposes. If, as Douglas and Marsh (1996) hypothesized, HBC are undergoing an alteration of life history and becoming more of a resident LCR population (with an attendant decline in the migrating portion of the population), then strategies to ensure the survivorship of annual cohorts and for providing carrying capacity in the mainstem may become increasingly more important for maintaining this small population, particularly because single cohort survivorship appears to already have the capacity to visibly influence the annual abundance of fish ≥ 150 mm (see Van Haverbeke 2006). For instance, some mainstem flow options, or timing of mainstem flow actions may be particularly damaging if performed during years characterized by frequent and large flooding events in the LCR when high numbers of age-0 and juvenile HBC are transported out in the mainstem. Although humpback chub is long lived, reductions of annual recruitment processes should be expected to exacerbate the situation of decline in a species whose adult abundance is low.

Contrary to the spring abundance trends, the abundance estimates obtained during the fall since 2000 for HBC ≥ 150 have not shown a decline compared to estimates in the 1990s. The spring abundance estimates are presumably more inclusive of the portion of the population that migrates between the mainstem Colorado River and the LCR for spawning activities, whereas the fall abundance estimates are presumably more representative of fish that reside year round (or over-winter) in the LCR. Because of this, it lends credence to the hypothesis that the decline in HBC abundance since the early 1990s has taken place in the portion of fish that migrate from the mainstem for spawning activities, and that this decline is being manifested in the observed declines in the spring spawning abundance in the LCR. It might also be hypothesized that an abundance of roughly 1,000 to 3,000 HBC ≥ 150 mm may be representative of the year round carrying capacity for HBC in the LCR (see Figure 24), although this number would be somewhat higher when including the fish that over-winter in the upper and lower reaches of the Chute Falls area.

Chute Falls Area HBC Abundance Estimate

The Chute Falls efforts probably represent the first robust attempt to obtain population abundance estimates for HBC above Lower Atomizer Falls. Although Douglas and Marsh (1996) present their population abundance estimates as being relevant from the Confluence to 14.9 rkm, it is probably more accurate to say that their estimates were relevant from the Confluence to 13.57 rkm, or to the base of Lower Atomizer Falls. Although the maps used by Douglas and Marsh (1996) would define 14.9 rkm as occurring slightly above Chute Falls, their sampling crews very seldom ventured above Lower Atomizer Falls (D. R. Van Haverbeke, pers. obs.). Fishing from the Confluence to the base of Lower Atomizer Falls was the standard and most generally practiced work routine. For instance, during the 1990s, a query of the GCMRC database revealed that Arizona State University personnel captured only 40 humpback chub between Lower Atomizer and Chute Falls in 18 hoop nets deployed in 1991-1992, but made no other captures, thereafter, despite some occasional sampling attempts.

For the Chute Falls trips of 2006, two length-stratified Chapman Peterson abundance estimates are provided for HBC ≥ 125 mm; one for the lower reach between Lower Atomizer Falls and the base of Chute Falls, and one for the upper reach above Chute Falls to rkm 18.1. In both reaches, K-S tests revealed that there was a significant difference in the length frequency distribution between marked and captured fish, and between the marked and recaptured fish, thus suggesting a length stratification procedure. Typically, these K-S tests provide an indication that some violation of the closure assumption may have occurred between the mark-recapture events; however, growth between the mark and recapture events was likely an important factor. The mean growth (between trips) of 208 recaptured HBC below Chute Falls was 4.9 mm (SE = ± 0.45 mm), while the 105 HBC recaptured above Chute Falls was 12.6 mm (SE = ± 0.58 mm). Some movement of fish may have also contributed to the failure of the K-S tests.

A length stratified abundance estimate of 707 (SE = 42) HBC ≥ 125 mm was provided for the lower reach. Of these, it was estimated that 328 (SE = 25) of these fish were ≥ 150 mm, and 206 (SE =18) of these fish were ≥ 200 mm. A length stratified abundance estimate of 440 (SE = 35) HBC ≥ 125 mm was provided for the upper reach. Of these, it was estimated that 255 (SE =11) of these fish were ≥ 150 mm, and 125 (SE =15) of these fish were ≥ 200 mm. Besides their own merit (e.g., providing an increased understanding of the Chute Falls translocation effort), these numbers represent an improved understanding of the overall abundance of HBC in the LCR. For example, adding the summed point estimate of 583 HBC ≥ 150 mm (see Table 23) from the Chute Falls reaches above Lower Atomizer to the spring 2006 abundance estimate of 2,261 HBC ≥ 150 mm below Lower Atomizer (see Table 8) results in 2,844 fish, which puts the sum just slightly above the upper confidence limit of 2,840 fish for spring of 2006. In addition, performing such simple summations as above is likely not the most acceptable or efficient method, since the Chute Falls abundance estimates were not performed concurrently with the spring abundance estimates.

Despite the aforementioned difficulties with obtaining an overall summed LCR population estimate, the Chute Falls efforts have led to important findings concerning the natural history of HBC. PIT tagging information supports the following hypotheses: 1) the upper reach above Chute Falls appears to still contain a one way closed population, 2) the lower reach is open, and 3) within the lower reach, Upper Atomizer Falls does not represent a barrier to upriver movement. Concerning the first hypothesis, there is still no evidence of any HBC ever migrating above Chute Falls from downriver (as of the date of our studies in 2006). However, 22 fish captured on these trips in the lower reach were known to have been translocated fish from above Chute Falls marked with Visible Elastomer Implant tags. These included 10 fish from the 2003 translocation, 6 fish from the 2004 translocation, and 6 fish from 2005 translocation. In addition, 7 more fish known to have been PIT tagged above Chute Falls were captured in the lower reach. Concerning the second and third hypotheses, 52 fish known to have been previously PIT tagged below Lower Atomizer Falls were captured throughout the lower reach, indicating that neither Lower Atomizer Falls (13.57 rkm), nor Upper Atomizer falls (13.87) represents a physical barrier to upriver movement of HBC.

The Chute Falls translocation efforts appear to represent a success story toward the recovery of HBC. The range of HBC within the LCR has been expanded at least another 4 rkm (14.1 to 18.1); provided that the translocated fish do not eventually vacate the area and swim to below Chute Falls. Given that there are still many HBC above Chute Falls that are < 150 mm (an estimated 185 fish if one subtracts the summed abundance of 255 HBC ≥ 150 mm above Chute Falls from the summed abundance estimate of 440 HBC ≥ 125 mm above Chute Falls), and that there appears to be spawning of HBC occurring above Chute Falls (i.e., ripe fish were observed), and that there appears to be a rich food source for HBC above Chute Falls (high densities of speckled dace), it may be that the Chute Falls translocation efforts could someday result in a significant increase in the abundance of HBC within the LCR.

Since the first translocation of age-0 HBC in 2003, an adult population of 125 fish ≥ 200 mm has resulted above Chute Falls. Considering that of 1,150 HBC from 50 to 100 mm that were translocated, 125 of these have already grown to ≥ 200 mm, this represents a high survivorship rate to adulthood (~10.9% thus far). , And this rate might be expected to increase as more of the translocated fish grow into adulthood. However, as with other translocated populations, one might expect an initial population increase to occur above Chute Falls, possibly followed by a decline as the translocated population equilibrates with its food resources. The markedly lower catch rates of speckled dace immediately below Chute Falls, as well as lower catch rates of fathead minnow, suggest that HBC utilize these species as a prey base, and indeed may be able to substantially crop their abundance.

RECOMMENDATIONS

Since the results over the past six years have important implications concerning the conservation and recovery of HBC, it is recommended that the Bureau of Reclamation and GCMRC continue to pursue options that may enhance native fish populations in Grand Canyon. Primary among these are the reasonable and prudent measures listed in the Final Biological Opinion for the Operation of Glen Canyon Dam (USFWS 1994, USBR 1995), and would include any management actions undertaken in the mainstem to help ensure high survival of annual cohorts.

Second, obtaining annual point abundance estimates for HBC via closed population mark-recapture methodologies is useful and should be continued. However, factors governing population dynamics of trend and abundance are complex. The use of an open population model (e.g., ASMR), which makes use of more extensive data collected over a longer period of time, and provides estimates of recruitment, mortality rates, and abundance trend is preferred (Kitchell et al. 2003) and may resolve more difficult questions. In other words, it is suggested to continue incorporating the base data from our annual LCR efforts into open population models for estimating the trend and abundance of HBC in Grand Canyon (Kitchell et al. 2003).

As an alternative to this approach, it has been advocated by the Upper Colorado River Endangered Fish Recovery Program to sample concurrently in the mainstem and in the LCR in order to obtain an overall closed population abundance estimate for the LCR population. The issues with this approach have been spelled out in detail by a panel of mark-recapture experts (Kitchell et al. 2003). Essentially, it is considered more efficient, more precise, and more representative of abundance and trend to utilize a multi-year open population model approach (e.g., ASMR) rather than a closed population model approach. Second, in order to run a concurrent estimate, intensive trammel netting in the mainstem will be required. This raises concerns about undue stress and mortality upon the adult fish residing in the mainstem. Entanglement gear, such as trammel nets, is known to be more stressful than entrapment gear, such as hoop nets (Hopkins and Cech 1992). Third, a switch towards a concurrent sampling methodology is expected to be costly, and is viewed by some as not making use of the best available scientific information (USGS 2004). For all of the above reasons, it is suggested that GCMRC continue its current strategy of obtaining closed population estimates in the LCR, and incorporating these data, as well as other mainstem data, into open population models.

Third, it is recommended that sampling activities are continued in the LCR during both spring and fall months. Within the past several years, a significant amount of effort has been put forth to design and refine a mark-recapture program that has ultimately resulted in a defensible and robust program. In addition, a significant number of new tags are inserted into fish both during the spring and fall trips, as well as recaptured fish being recorded - both of which are used to feed the ASMR model. To discontinue either the spring or the fall efforts might be expected to have adverse consequences on the ASMR model.

Fourth, it is suggested to continue the mark recapture efforts in the Chute Falls area, both in the lower and upper reaches. This will serve to closely track the newly translocated population of HBC, and also serves to compliment the abundance estimates of HBC below 13.56 rkm, particularly those obtained in the spring. While it would be desirable to conduct the mark-recapture efforts in the Chute Falls area concurrently with the spring mark-recapture efforts, there are logistical and safety concerns which will dictate otherwise (i.e., the Chute Falls area is unsafe to work in during flooding season).

DATA ARCHIVING

The data for the two spring trips are archived at the Grand Canyon Monitoring and Research Center in six MS Access files entitled: LC20060330_Boulders.mdb, LC20060330_Coyote.mdb, LC20060330_Salt.mdb, LC20060425_Boulders.mdb, LC20060425_Coyote.mdb, and LC20060425_Salt.mdb.

The data for these trips are archived at the Grand Canyon Monitoring and Research Center in six MS Access files entitled: LC20060919_Boulders.mdb, LC20060919_Coyote.mdb, LC20060919_Salt.mdb, LC20061019_Boulders.mdb, LC20061019_Coyote.mdb, and LC20061019_Salt.mdb.

The data for the two Chute Falls trips are archived at the Grand Canyon Monitoring and Research Center in two MS Access files entitled LC20060523.mdb and LC20060628.mdb.

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Table 1. Personnel who participated on trips, listed by trip date, reach (i.e. Salt, Coyote, Boulders, and Lower Atomizer to 18.1 rkm) and agency (U.S. Fish and Wildlife Service [USFWS], SWCA Inc. [SWCA], and volunteers [Vol.]). Little Colorado River 2006.

	Salt Reach	Coyote Reach	Boulders Reach
30 March to 7 April	Dennis Stone [USFWS] Emily Yates [Vol.] Vernard Mantegna [Vol.]	Pamela Sponholtz [USFWS] David Mueller [USFWS] Darrick Weissenflugh [Vol.]	Dewey Wesley [USFWS] Kevin Serrato [SWCA] Mat Flores [Vol.]
25 April to 5 May	Dennis Stone [USFWS] Mike Hawkshaw [Vol.] Melissa Cheung [Vol.]	Pam Sponholtz [USFWS] Josh David [USFWS] Kate Sparks [Vol.]	David Van Haverbeke [USFWS] Dan Gwinn [GCMRC]
19 to 28 September	Dennis Stone [USFWS] Suzzanne Rhoades [SWCA] Andrea Holland-Sears [Vol.]	Pam Sponholtz [USFWS] Joe Barnett [USFWS] Bill Persons [AGFD]	Dewey Wesley [USFWS] Christine Hirsch [Vol.] Misti Schriner [Vol.]
19 to 27 October	Dennis Stone [USFWS] Mary Cashman [Vol.] Abbey Spotskey [Vol.]	David Van Haverbeke [USFWS] Jim Walters [Vol.] Mary Zylo [Vol.]	Dewey Wesley [USFWS] Jeff Houser [USGS] Caleb Snow [Vol.]

Chute Falls Trips

	Lower Atomizer to 18.1 rkm Reach
23 to 26 May	Pam Sponholtz [USFWS] Dennis Stone [USFWS] Lauren Ris [USFWS] Kara Hilwig [SWCA] Anne Morton [Vol.] David Mueller [Vol.]
28 June to 3 July	Pam Sponholtz [USFWS] Kara Hilwig [SWCA] Angie Able [GCMRC] David Ward [AZGFD] Cooper Carothers [Vol.]

Table 2. Habitat characteristics for hoop nets set in Little Colorado River, 2006.

Shoreline habitat	Hydraulic Unit	Substrate	Cover type
cutbank	backwater	clay-silt-marle (< 0.06 mm)	boulders
debris fan boulders	eddy (counter current)	silt-sand (0.07-0.10 mm)	ledge, or lateral cover
ledge	glide	sand (0.11-2.0 mm)	none
sand bar	pool (still)	gravel (2.1-15 mm)	undetermined
silt	rapid	pebble (16-31 mm)	vegetative cover
talus	return channel	rock (32-100 mm)	
travertine dam	riffle	cobble (101-255 mm)	
vegetated shoreline	run	small boulder (256-999 mm)	
		boulder (1-3 m)	
		large boulder (> 3 m)	
		bedrock	

Table 3. Summary of fishing effort by trip, reach, number of hoop net sets, hours of effort, humpback chub (HBC) catch, and HBC catch per unit effort (CPE; fish/net-hr); Little Colorado River, spring 2006.

		Effort		HBC	HBC
Trip	Reach	Sets	Hours	Catch	CPE
April					
	Salt	150	3,732	661	0.177
	Coyote	150	3,401	599	0.176
	Boulders	147	3,456	463	0.134
	Total	447	10,589	1,723	0.163
May					
	Salt	180	4,393	1,053	0.240
	Coyote	180	4,123	991	0.240
	Boulders	180	4,081	1,096	0.269
	Total	540	12,597	3,140	0.249
Grand Total		987	23,186	4,863	0.210

Table 4. Summary of fish captured by trip, reach, and species; Little Colorado River, spring 2006.

		Species*												
Trip	Reach	BBH	BHS	BRT	CCF	CRP	FHM	FMS	GSF	HBC	PKF	RSH	SPD	Total
April														
	Salt	2	21			1	477	2		661			81	1,245
	Coyote	6	24		2	4	266	12		599			76	989
	Boulders	1	90		2	4	391	35		463		1	396	1,383
	Total	9	135	0	4	9	1,134	49		1,723	0	1	553	3,617
May														
	Salt	7	208	1	1	1	503	3		1,053			220	1,997
	Coyote	3	384		2	1	605	22	2	991	1	2	137	2,150
	Boulders	2	425		3	3	404	107		1,096		3	651	2,694
	Total	12	1,017	1	6	5	1,512	132	2	3,140	1	5	1,008	6,841
Grand Total		21	1,152	1	10	14	2,646	181	2	4,863	1	6	1,561	10,458

* BBH = black bullhead (*Ameiurus melas*); BHS = bluehead sucker (*Catostomus discobolus*); BRT = brown trout (*Salmo trutta*); CCF = channel catfish (*Ictalurus punctatus*); CRP = common carp (*Cyprinus carpio*); FHM = fathead minnow (*Pimephales promelas*); FMS = flannelmouth sucker (*Catostomus latipinnis*); GSF = green sunfish (*Lepomis cyanellus*); HBC = humpback chub (*Gila cypha*); PKF = plains killifish (*Fundulus zebrinus*); RSH = red shiner (*Cyprinella lutrensis*); SPD = speckled dace (*Rhinichthys osculus*).

Table 5. Number of humpback chub marked and unmarked during the recapture event by total length strata; Little Colorado River, spring 2006.

Length strata	Unmarked	Marked	Mark rate
150-199	225	53	19.06%
200-249	128	65	33.68%
250-299	51	10	16.39%
300-349	21	6	22.22%
350-399	27	2	6.90%
400-449	22	3	12.00%
Totals	474	139	22.68%

Ho: Mark rate among length strata is the same.

Reject null hypothesis (χ^2 = 22.51, df = 5, $p < 0.001$)

Table 6. Number of humpback chub marked and unmarked during the recapture event by reach; Little Colorado River, spring 2006.

Reach	Unmarked	Marked	Mark rate
Salt	217	121	35.80%
Coyote	145	6	3.97%
Boulder	112	12	9.68%
Total	474	139	22.68%

Ho: Mark rate among the reaches is the same.

Reject null hypothesis (χ^2 = 187.71, df = 2, $p < 0.0001$)

Table 7. Length stratified Chapman modified Petersen abundance estimate for humpback chub ≥ 150 mm by two geographic strata (i.e., Salt reach and pooled Coyote and Boulders reaches); Little Colorado River, spring 2006.

Abundance of HBC >=150 mm TL in Salt reach

						95% Confidence Interval	
Length (mm)	Marked	Captured	Recaptured	N	SE	Lower	Upper
150 - 290	246	301	113	653	35	584	723
> 290	38	37	8	164	40	85	242
Sum Strata				817	54	713	921

Abundance of HBC >=150 mm TL in pooled Coyote and Boulders reaches

						95% Confidence Interval	
Length (mm)	Marked	Captured	Recaptured	N	SE	Lower	Upper
150 - 200	48	158	11	648	150	353	943
> 200	53	117	7	796	237	332	1,259
Sum Strata				1,444	280	894	1,993

Summed abundance of HBC >=150 mm TL in all reaches

						95% Confidence Interval	
	Marked	Captured	Recaptured	N	SE	Lower	Upper
Total sum	385	613	139	2,261	285	1,701	2,820

Table 8. Spring abundance estimates for humpback chub ≥ 150 mm by year and month; Little Colorado River.

Date	N	SE	95 % Confidence Interval Lower	95 % Confidence Interval Upper	Reach (rkm)	# per km
April 1992	5,555	671	4,416	7,067	0 - 13.57	409
May 1992	4,363	1,216	2,594	7,523	0 - 13.57	322
June 1992	4,384	458	3,573	5,381	0 - 13.57	323
May/June 2001	2,082	242	1,607	2,557	0 - 13.57	153
April/May 2002	2,666	463	1,759	3,573	0 - 13.57	196
April/May 2003	3,419	480	2,478	4,360	0 - 13.57	252
April/May 2004	2,334	411	1,529	3,138	0 - 13.57	172
April/May 2005	2,476	665	1,173	3,779	0 - 13.57	182
April/May 2006	2,261	285	1,702	2,820	0 - 13.57	167

1992 estimates are from Douglas and Marsh (1996), 2001 estimate is from Van Haverbeke and Coggins (2003), 2002 estimate is from Van Haverbeke (2003); 2003 estimate is from Van Haverbeke (2004), 2004 estimate is from Van Haverbeke (2005).

Table 9. Length stratified Chapman modified Petersen abundance estimate for humpback chub ≥ 200 mm by two geographic strata (i.e., Salt reach and pooled Coyote and Boulders reaches); Little Colorado River, spring 2006.

Abundance of HBC >=200 mm total length in Salt reach

							95% Confidence Interval	
Length stratification (mm)	Marked	Captured	Recaptured	P	N	SE	Lower	Upper
150 - 290	246	301	113					
200 - 290	129	180	71	0.55	358	37	286	430
>290	38	37	8	1	164	40	85	242
Sum Strata					522	54	416	628

Abundance of HBC >=200 mm total length in pooled Coyote and Boulders reaches

						95% Confidence Interval	
Length stratification (mm)	Marked	Captured	Recaptured	N	SE	Lower	Upper
>=200	54	118	7	817	243	340	1,294

Summed abundance of HBC >=200 mm total length in all reaches

			95% Confidence Interval	
	N	SE	Lower	Upper
Total sum	1,339	249	850	1,828

Table 10. Spring abundance estimates for humpback chub ≥ 200 mm by year and month; Little Colorado River.

			95 % Confidence Interval			
Date	Abundance Estimate	SE	Lower	Upper	Reach (rkm)	# per km
May/June 2001	1,470	240	1,000	1,940	0 - 13.57	108
April/May 2002	2,002	462	1,096	2,908	0 - 13.57	147
April/May 2003	1,421	245	941	1,901	0 - 13.57	104
April/May 2004	1,816	394	1,044	2,588	0 - 13.57	134
April/May 2005	1,541	551	461	2,621	0 - 13.57	113
April/May 2006	1,339	249	851	1,827	0 - 13.57	98

2001 estimate is from Van Haverbeke and Coggins (2003), 2002 estimate is from Van Haverbeke (2003), 2003 estimate is from Van Haverbeke (2004), 2004 estimate from Van Haverbeke 2005, 2005 estimate is from Van Haverbeke 2006.

Table 11. Spring abundance estimates of bluehead sucker by year, month and reach, Little Colorado River.

Date and reach	Length (mm)	Marked	Captured	Recaptured	N	SE	95% Confidence Intervals* Lower	Upper
April/May 2006 All three reaches	>= 184	105	695	5	12,295	4,495	3,486	21,104
April/May 2006 (Boulders and Coyote)	>= 184	92	590	5	9,160	3,332	2,629	15,690
April/May 2006 (Boulders only)	>= 184	74	309	4	4,649	1,819	1,083	8,215
April/May 1993 (All three reaches)	>= 182	342	130	7	5,616	1,793	2,102	9,130
April/May 1993 (Salt and Coyote)	>= 182	291	97	6	4,087	1,376	1,390	6,784
April/May 1993 (Salt only)	>= 182	135	62	4	1,713	659	421	3,004

*In order to be 95% confident that the bias of the abundance estimate is negligible, a minimum of 7 recaptures is considered necessary (Seber 2002).

Table 12. Summary of fishing effort by trip, reach, number of hoop net sets, hours of effort, humpback chub (HBC) catch, and HBC catch per unit effort (CPE; fish/net-hr); Little Colorado River, fall 2006.

		Effort		HBC	HBC
Trip	Reach	Sets	Hours	Catch	CPE
September					
	Salt	180	4,343	132	0.030
	Coyote	180	4,097	90	0.022
	Boulders	180	4,103	128	0.031
	Total	540	12,543	350	0.028
October					
	Salt	180	4,349	134	0.031
	Coyote	180	4,089	120	0.029
	Boulders	180	4,151	113	0.027
	Total	540	12,589	367	0.029
Grand Total		1,080	25,132	717	0.029

Table 13. Summary of fish captured by trip, reach, and species; Little Colorado River, fall 2006.

		Species*												
Trip	Reach	BBH	BHS	CCF	CRP	FHM	FMS	GSF	HBC	PKF	RBT	RSH	SPD	Total
September														
	Salt	43	2		10	2	1		132				14	204
	Coyote	6	1	1	5	1	1		90				6	111
	Boulders	4	13	1	5	3	6		128				21	181
	Total	53	16	2	20	6	8	0	350	0	0	0	41	496
October														
	Salt	31	4	1	20		2		134				21	213
	Coyote	7	1	1	12	3	3		120				20	167
	Boulders	3	4		1	3	13		113				20	157
	Total	41	9	2	33	6	18	0	367	0	0	0	61	537
Grand Total		94	25	4	53	12	26	0	717	0	0	0	102	1,033

* BBH = black bullhead (*Ameiurus melas*); BHS = bluehead sucker (*Catostomus discobolus*); CCF = channel catfish (*Ictalurus punctatus*); CRP = common carp (*Cyprinus carpio*); FHM = fathead minnow (*Pimephales promelas*); FMS = flannelmouth sucker (*Catostomus latipinnis*); GSF = green sunfish (*Lepomis cyanellus);* HBC = humpback chub (*Gila cypha*); PKF = plains kiilifish (*Fundulus zebrinus*); RBT = rainbow trout (*Oncorhynchus mykiss*); RSH = red shiner (*Cyprinella lutrensis*); SPD = speckled dace (*Rhinichthys osculus*).

Table 14. Number of humpback chub marked and unmarked during the recapture event by total length strata; Little Colorado River, fall 2006.

Length strata	Unmarked	Marked	Mark rate
150-199	105	14	11.76%
200-249	65	11	14.47%
250-299	26	4	13.33%
300-349	4	1	20.00%
350-399	3	0	0.00%
400-449	6	0	0.00%
Totals	209	30	12.55%

Ho: Mark rates among length strata is the same.

Accept null hypothesis (χ^2 = 1.88 df = 5, p = 0.865).

Table 15. Number of humpback chub marked and not marked during the recapture event by reach; Little Colorado River, fall 2006.

Reach	Unmarked	Marked	Mark rate
Salt	96	20	17.24%
Coyote	65	5	7.14%
Boulder	48	5	9.43%
Total	209	30	12.55%

Ho: Mark rates among length strata is the same.

Accept null hypothesis (χ^2 = 5.48, df = 2, p = 0.065)

Table 16. Length stratified Chapman modified Petersen abundance estimate of humpback chub ≥ 150 mm; Little Colorado River, fall 2006.

						95% Confidence Interval	
Length (mm)	Marked	Captured	Recaptured	N	SE	Lower	Upper
150-210	104	142	21	682	116	453	910
> 210	126	97	9	1,244	341	575	1,913
Sum Strata				1,925	361	1,218	2,632

Table 17. Fall abundance estimates of humpback chub $\geq$ 150 mm ($\geq$ 135 mm in 2000) by year and month in the lower 13.57 km of the Little Colorado River.

Date	Abundance Estimate	SE	95% Confidence Interval Lower	Upper	Size (mm)	# per km
September 1991	1,771	300	1,296	2,492	>= 150 mm	130
October 1991	2,038	518	1,276	3,368	>= 150 mm	150
November 1991	1,989	489	1,264	3,235	>= 150 mm	146
September 1992	1,950	1,381	598	6,908	>= 150 mm	143
October 1992	1,099	60	990	1,224	>= 150 mm	81
November 1992	1,417	408	839	2,500	>= 150 mm	104
October/November 2000	1,590	297	992	2,552	>= 135 mm	117
October/November 2001	1,064	33	999	1,129	>= 150 mm	78
October/November 2002	2,774	209	2,364	3,184	>= 150 mm	204
September/October 2003	1,862	206	1,459	2,265	>= 150 mm	137
September/October 2004	2,565	519	1,548	3,582	>= 150 mm	189
September/October 2005	1,523	113	1,302	1,744	>= 150 mm	112
September/October 2006	1,925	361	1,217	2,633	>= 150 mm	142

1991 and 1992 estimates are from Douglas and Marsh (1996); 2000 estimate is from Coggins and Van Haverbeke (2001); 2001 estimate is from Van Haverbeke and Coggins (2003); 2002 estimate is from Van Haverbeke (2003); 2003 estimate is from Van Haverbeke (2004); 2004 estimate is from Van Haverbeke (2005), 2005 estimate is from Van Haverbeke (2006).

Table 18. Fall abundance estimates of humpback chub $\geq$ 200 mm by year and month in the lower 13.57 rkm of the Little Colorado River.

			95% Confidence Interval		
Date	Abundance Estimate	SE	Lower	Upper	# per km
October/November 2001	483	48	389	577	36
October/November 2002	839	73	696	982	62
September/October 2003	897	116	670	1,124	66
September/October 2004	796	230	345	1,247	59
September/October 2005	511	60	393	629	38
September/October 2006	1,347	342	677	2,017	99

2001 estimate is from Van Haverbeke and Coggins (2003). 2002 estimate is from Van Haverbeke (2003), 2003 estimate is from Van Haverbeke (2004), 2004 estimate form Van Haverbeke (2005), 2005 estimate is from Van Haverbeke (2006).

Table 19. Summary of fishing effort by trip, reach, number of hoop net sets, hours of effort, humpback chub (HBC) catch, and HBC catch per unit effort (CPE; fish/net-hr); Little Colorado River, summer 2006.

		Effort		HBC	HBC
Trip	Reach	Sets	Hours	Catch	CPE
May					
	Upper (14.1-18.1 rkm)	101	2,400	262	0.109
	Lower (13.57-14.1 rkm)	48	1,065	242	0.227
	Total	149	3,465	504	0.145
June					
	Upper (14.1-18.1 rkm)	99	2,361	236	0.100
	Lower (13.57-14.1 rkm)	51	1,167	510	0.437
	Total	150	3,528	746	0.211
Grand Total		299	6,993	1,250	0.179

Table 20. Summary of fish captured by trip, reach, and species; Little Colorado River, summer 2006.

		Species*												
Trip	Reach	BBH	BHS	BRT	CCF	CRP	FHM	FMS	GSF	HBC	PKF	RSH	SPD	Total
May														
	Upper (14.1-18.1 rkm)	18				60	71			262	1		5,469	5,881
	Lower (13.57-14.1 rkm)	1				9	6			422			78	516
	Total	19	0	0	0	69	77	0		684	1	0	5,547	6,397
June														
	Upper (14.1-18.1 rkm)	13				22	33			236			6,569	6,873
	Lower (13.57-14.1 rkm)	4				2	20	1		510			147	684
	Total	17	0	0	0	24	53	1	0	746	0	0	6,716	7,557
Grand Total		36	0	0	0	93	130	1	0	1,430	1	0	12,263	13,954

* BBH = black bullhead (*Ameiurus melas*); BHS = bluehead sucker (*Catostomus discobolus*); CCF = channel catfish (*Ictalurus punctatus*); CRP = common carp (*Cyprinus carpio*); FHM = fathead minnow (*Pimephales promelas*); FMS = flannelmouth sucker (*Catostomus latipinnis*); GSF = green sunfish (*Lepomis cyanellus);* HBC = humpback chub (*Gila cypha*); PKF = plains kiilifish (*Fundulus zebrinus*); RBT = rainbow trout (*Oncorhynchus mykiss*); RSH = red shiner (*Cyprinella lutrensis*); SPD = speckled dace (*Rhinichthys osculus*).

Table 21. Number of humpback chub marked and unmarked during the recapture event by total length strata in the lower reach below Chute Falls (13.57 to 14.1 rkm) and upper reach above Chute Falls (14.1 to 18.1 rkm) reaches; Little Colorado River, 28 June to 3 July trip, 2006.

Lower Reach Length strata	Unmarked	Marked	Mark rate
100-149	95	54	36.24%
150-199	77	46	37.40%
200-249	14	44	75.86%
250-299	16	49	75.38%
300-349	6	11	64.71%
350-400	3	4	57.14%
Totals	211	208	49.64%

Ho: Mark rates among length strata is the same.
Reject null hypothesis (χ^2 = 52.96, df = 5, $p < 0.001$)

Upper Reach Length strata	Unmarked	Marked	Mark rate
100-149	18	14	43.75%
150-199	41	45	52.33%
200-249	19	27	58.70%
250-299	12	18	60.00%
300-349	2	1	33.33%
Totals	92	105	53.30%

Ho: Mark rates among length strata is the same.
Accept null hypothesis (χ^2 = 2.76, df = 4, $p = 0.598$)

Table 22. Length stratified Chapman modified Petersen abundance estimates for humpback chub ≥ 125 mm in lower reach (13.67 to 14.1 rkm) and upper reach (14.1 to 18.1 rkm), Little Colorado River, summer 2006.

Abundance of humpback chub >=125 mm total length in lower reach below Chute Falls

						95% Confidence Interval	
Length (mm)	Marked	Captured	Recaptured	N	SE	Lower	Upper
100 - 140	94	67	22	280	41	200	359
> 140	226	352	186	428	9	410	445
Sum Strata				707	42	626	789

Abundance of humpback chub >=125 mm total length in upper reach above Chute Falls

						95% Confidence Interval	
Length (mm)	Marked	Captured	Recaptured	N	SE	Lower	Upper
100 - 150	86	36	15	200	33	135	265
> 150	134	161	90	239	9	221	258
Sum Strata				440	35	372	507

Summed abundance of humpback chub >=125 mm total length in lower and upper reaches combined.

						95% Confidence Interval	
	Marked	Captured	Recaptured	N	SE	Lower	Upper
Total sum	540	616	313	1,147	54	1,041	1,253

Table 23. Abundance estimate of humpback chub ≥ 150 mm in lower reach below Chute Falls (13.57 to 14.1 rkm) and in upper reach above Chute Falls (14.1 to 18.1 rkm); Little Colorado River, summer 2006.

Abundance of humpback chub >=150 mm total from lower reach below Chute Falls

							95% Confidence Interval	
Length stratification (mm)	Marked	Captured	Recaptured	P	N	SE	Lower	Upper
>=141	226	352	186					
>=150	185	270	154	0.77	328	25	279	378

Abundance of humpback chub >=150 mm total length from upper reach above Chute Falls

						95% Confidence Interval	
Length stratification (mm)	Marked	Captured	Recaptured	N	SE	Lower	Upper
>=150	141	165	91	255	11	235	276

Summed abundance of humpback chub >=150 mm total length from lower and upper reaches combined

			95% Confidence Interval	
	N	SE	Lower	Upper
Total sum	583	27	530	637

Table 24. Abundance estimates of humpback chub ≥ 200 mm in lower reach below Chute Falls (13.57 to 14.1 rkm) and in upper reach above chute Falls (14.1 to 18.1 rkm); Little Colorado River, summer 2006.

Abundance of humpback chub >=200 mm from lower reach below Chute Falls

							95% Confidence Interval	
Length stratification (mm)	Marked	Captured	Recaptured	P	N	SE	Lower	Upper
>=141	226	352	186					
>=200	150	147	108	0.48	206	18	172	241

Abundance of humpback chub >=200 mm total length from upper reach above Chute Falls

							95% Confidence Interval	
Length stratification (mm)	Marked	Captured	Recaptured	P	N	SE	Lower	Upper
>=150	141	165	91					
>=200	72	79	46	0.49	125	15	95	154

Summed abundance of humpback chub >=200 mm total length from lower and upper reaches combined

			95% Confidence Interval	
	N	SE	Lower	Upper
Total sum	331	23	285	376

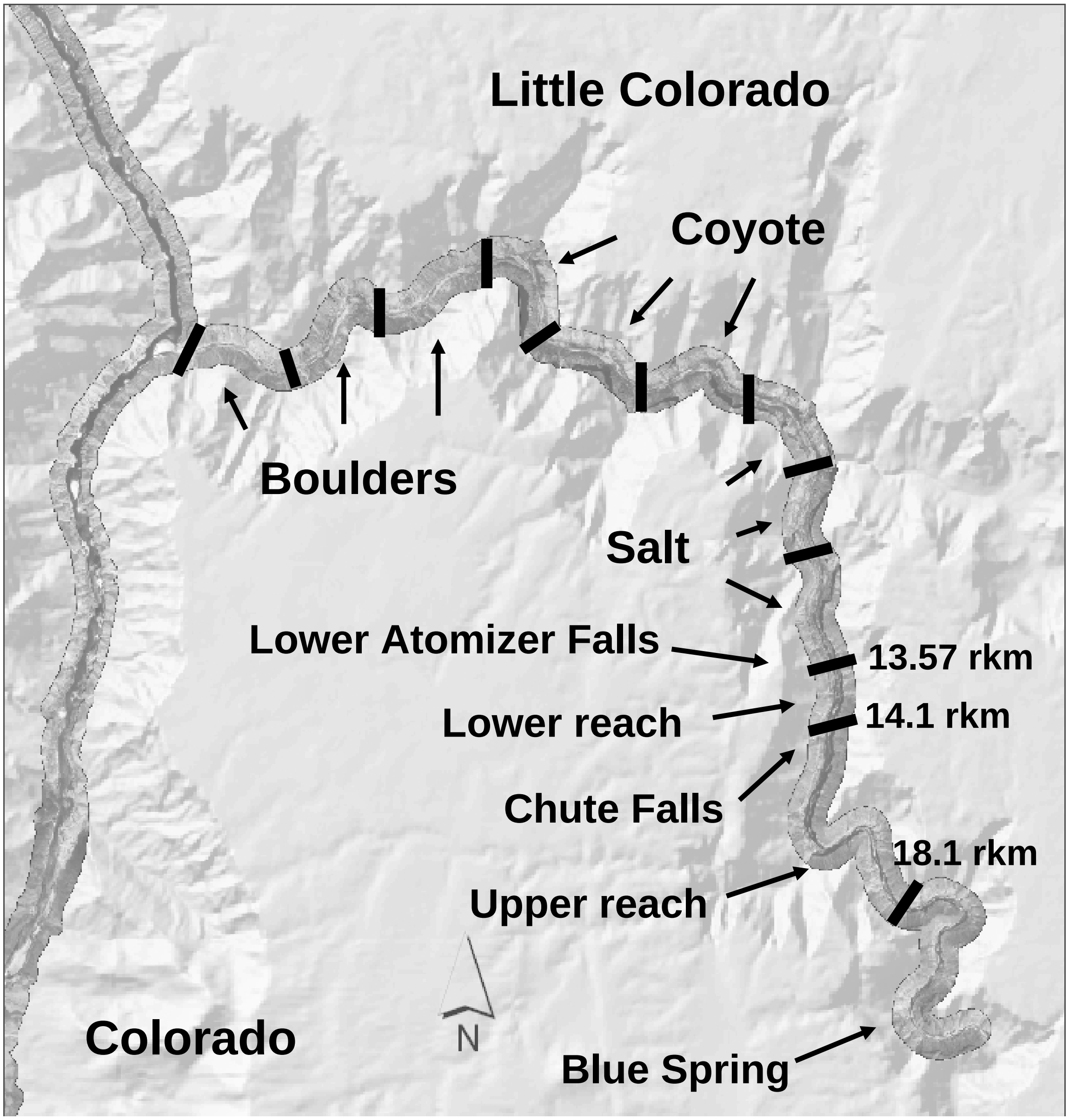


Figure 1. Map of the study sites, showing Salt, Coyote and Boulders reaches and lower and upper reaches of study area between Lower Atomizer Falls and 18.1 rkm; Little Colorado River.

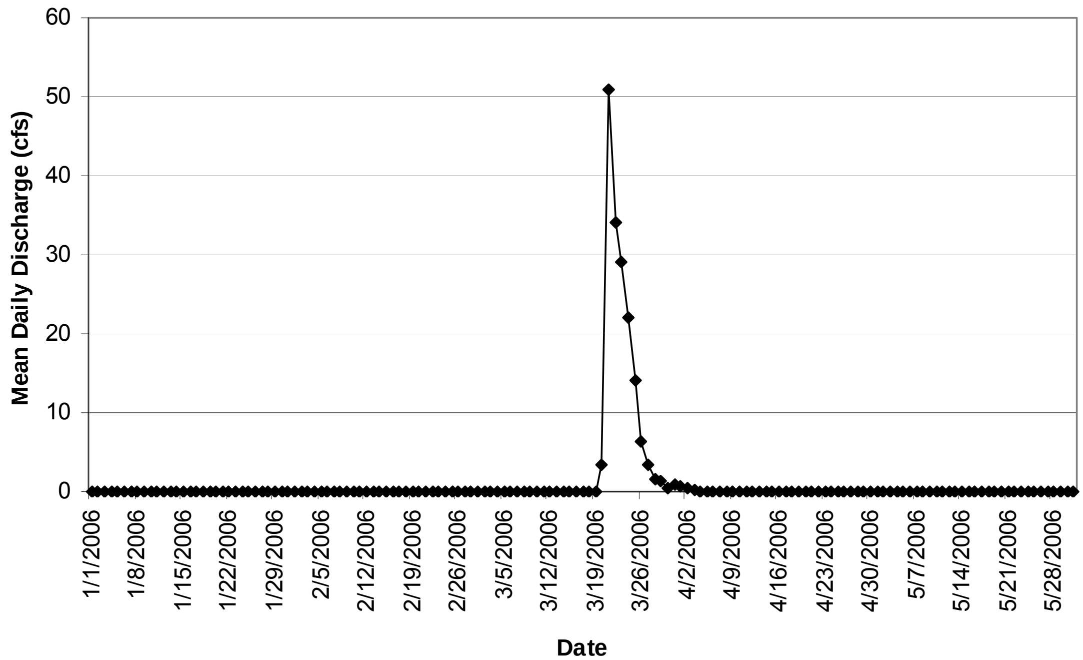


Figure 2. Provisional mean daily discharge (cubic feet/second) from USGS gage station 0904200; Little Colorado River, Arizona.

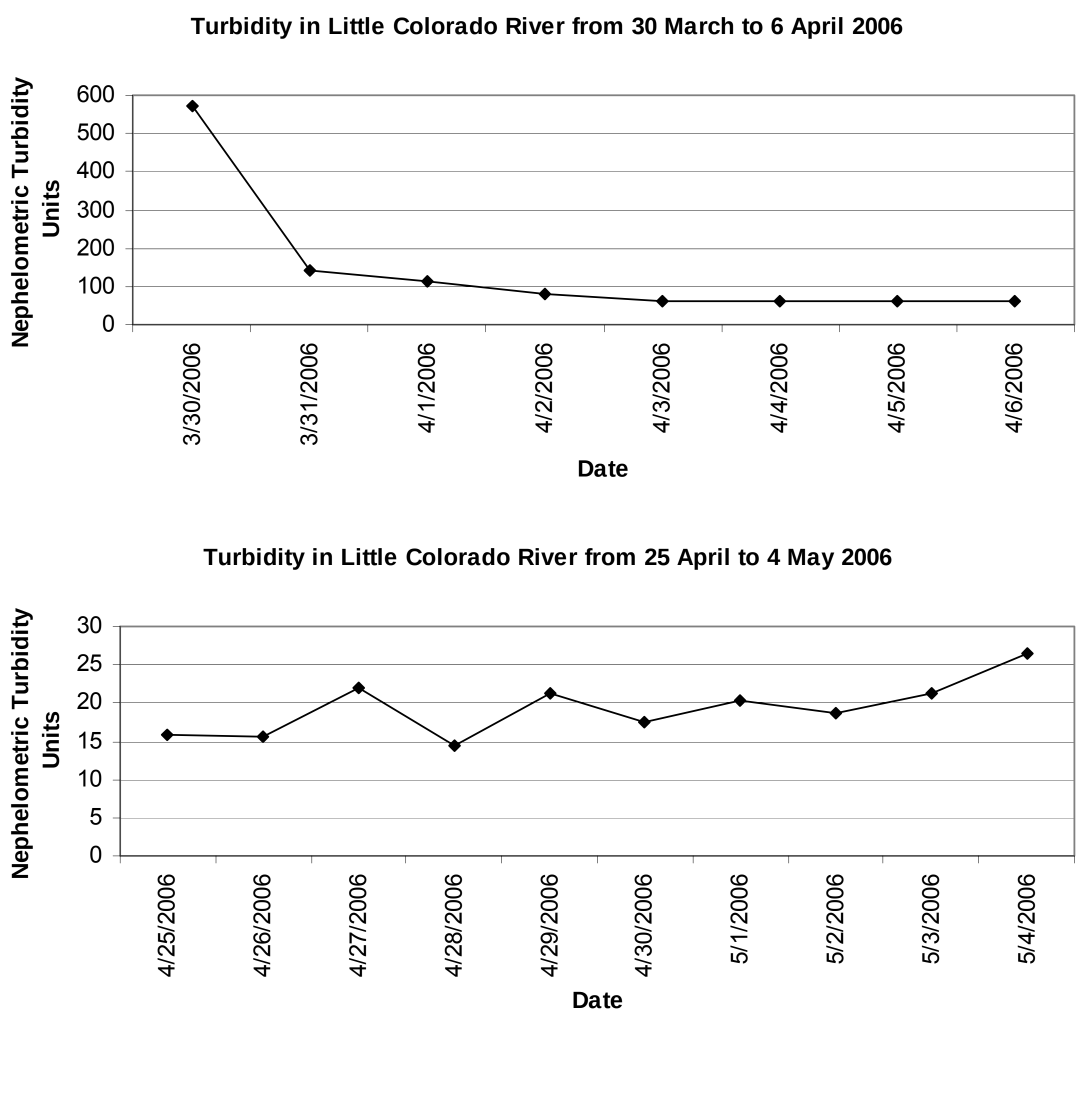


Figure 3. Turbidity readings taken in the Little Colorado River during spring 2006.

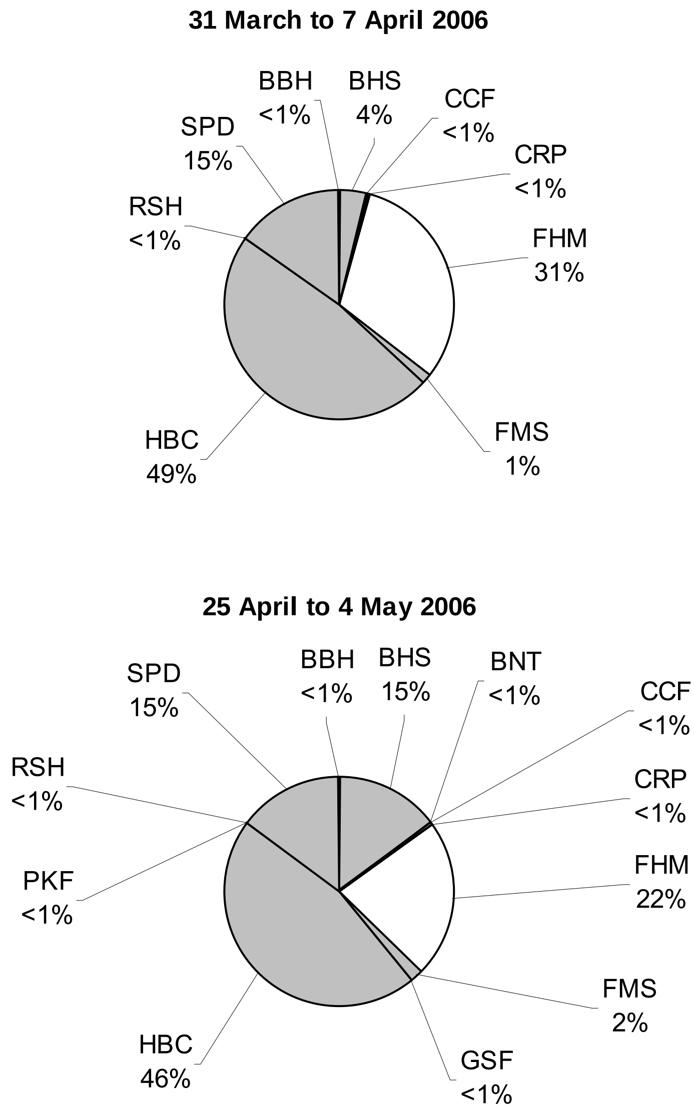
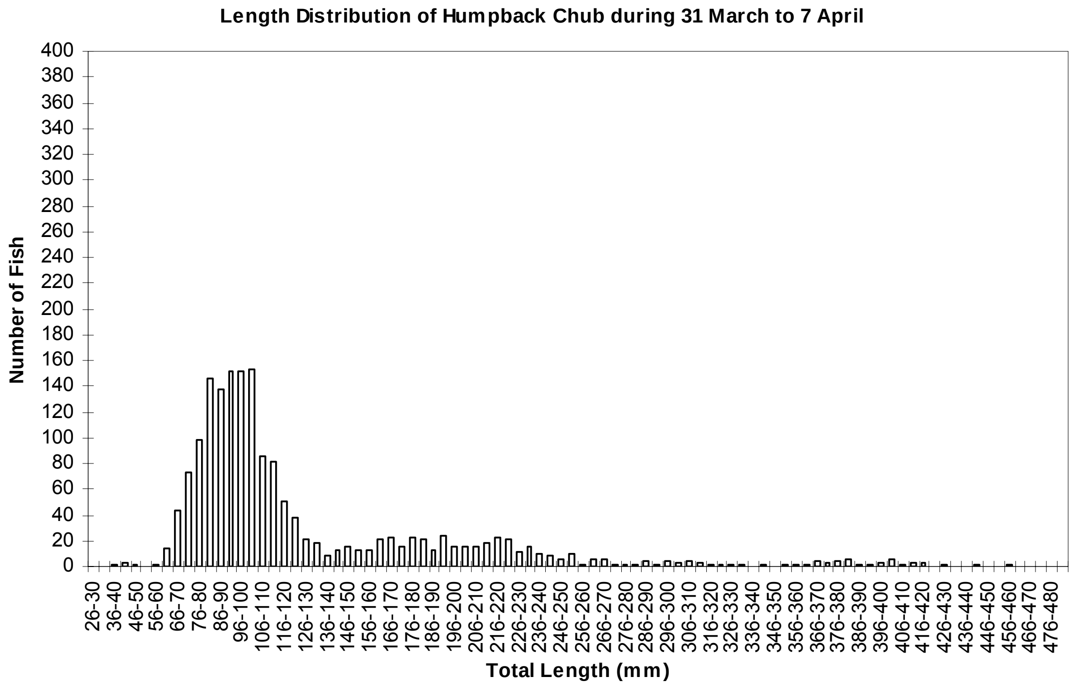


Figure 4. Observed species compositions of all fish captured. Shaded portions are native fish; Little Colorado River, spring 2006.

BBH = black bullhead (*Ameiurus melas*); BHS = bluehead sucker (*Catostomus discobolus*); BNT = brown trout (*Salmo trutta*); CCF = channel catfish (*Ictalurus punctatus*); CRP = common carp (*Cyprinus carpio*); FHM = fathead minnow (*Pimephales promelas*); FMS = flannelmouth sucker (*Catostomus latipinnis*); GSF = green sunfish (*Lepomis cyanellus*); HBC = humpback chub (*Gila cypha*); PKF = plains killifish (*Fundulus zebrinus*); RSH = red shiner (*Cyprinella lutrensis*); SPD = speckled dace (*Rhinichthys osculus*).



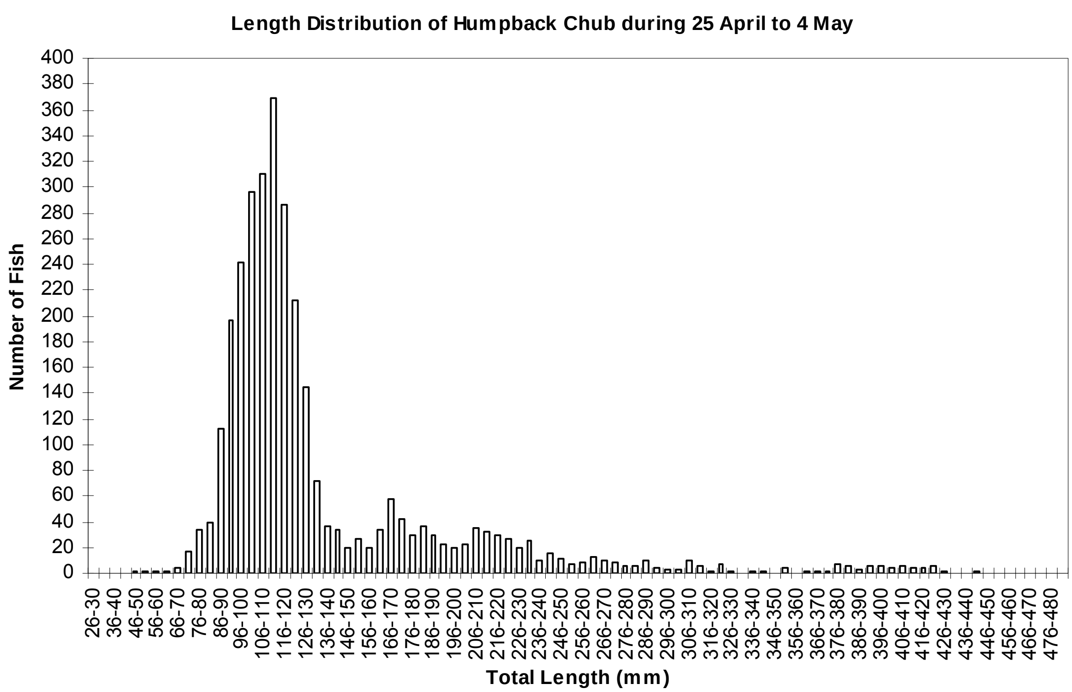


Figure 5. Total length frequency distributions of all humpback chub captured; Little Colorado River, spring 2006.

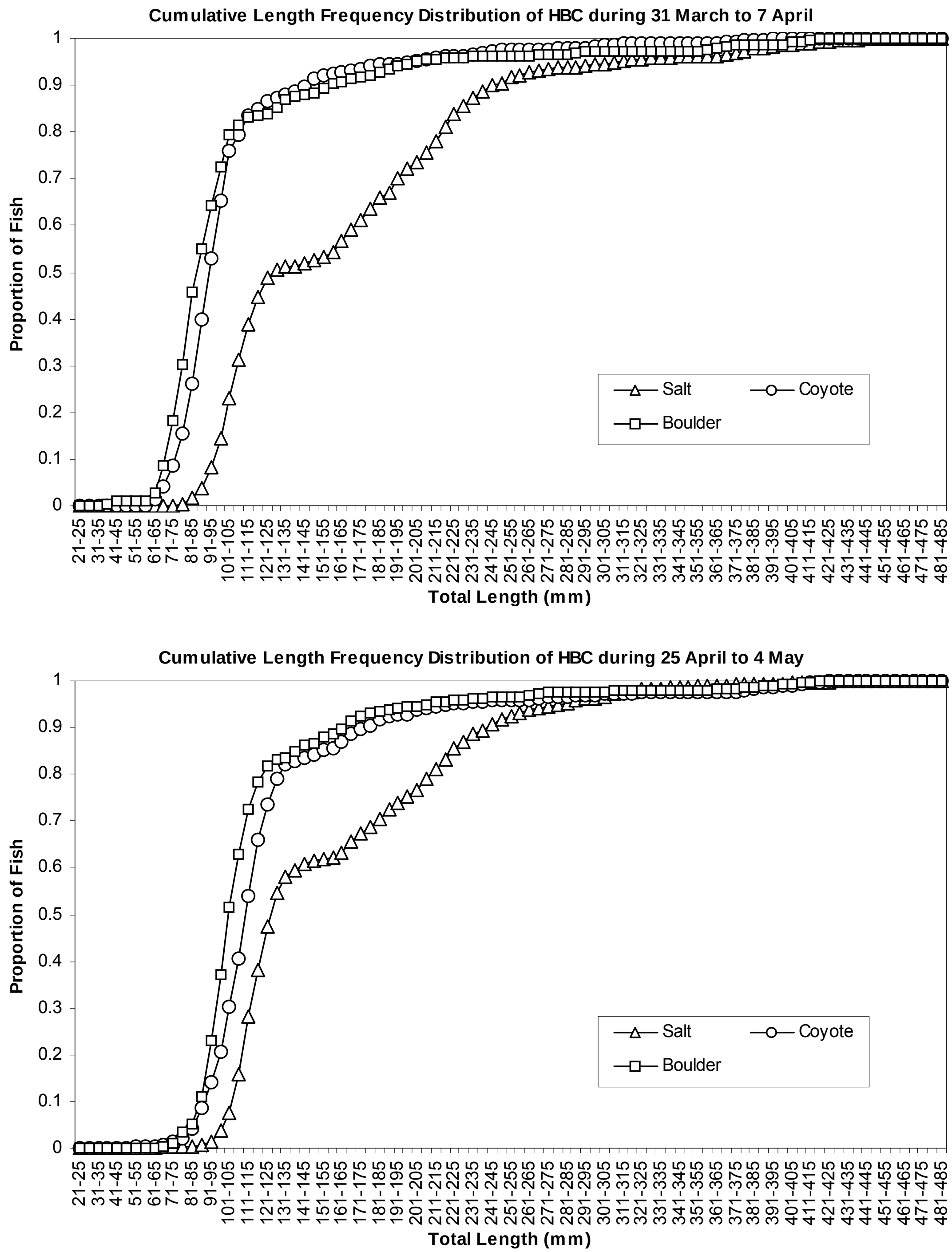
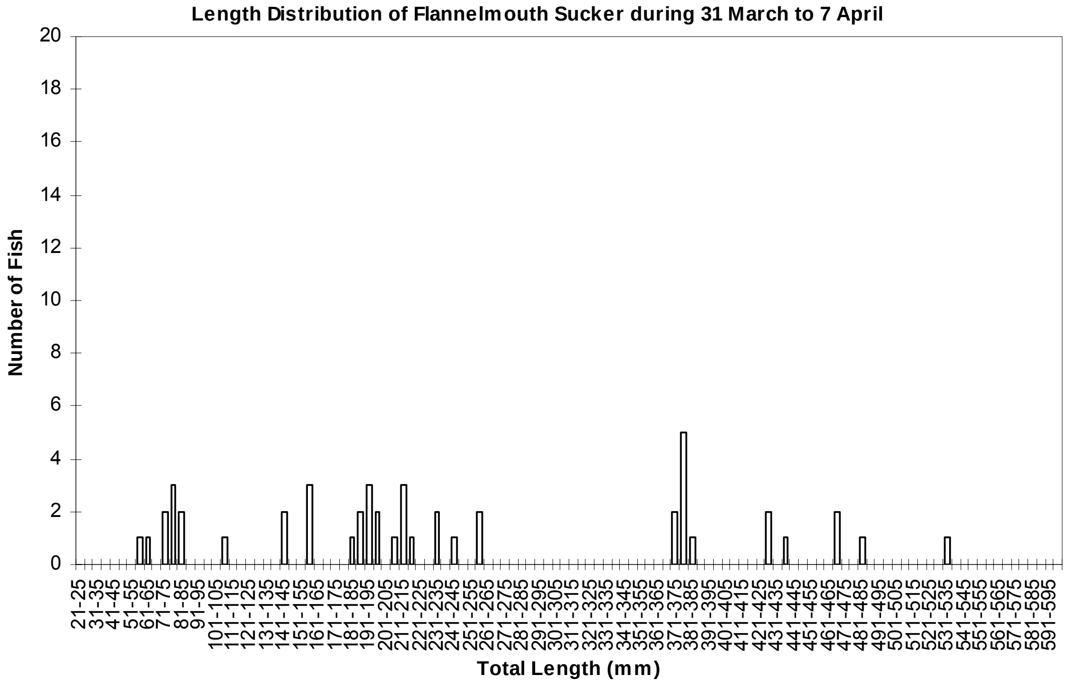


Figure 6. Cumulative length frequencies of all HBC captured in Salt, Coyote and Boulders reaches; Little Colorado River, spring 2006.



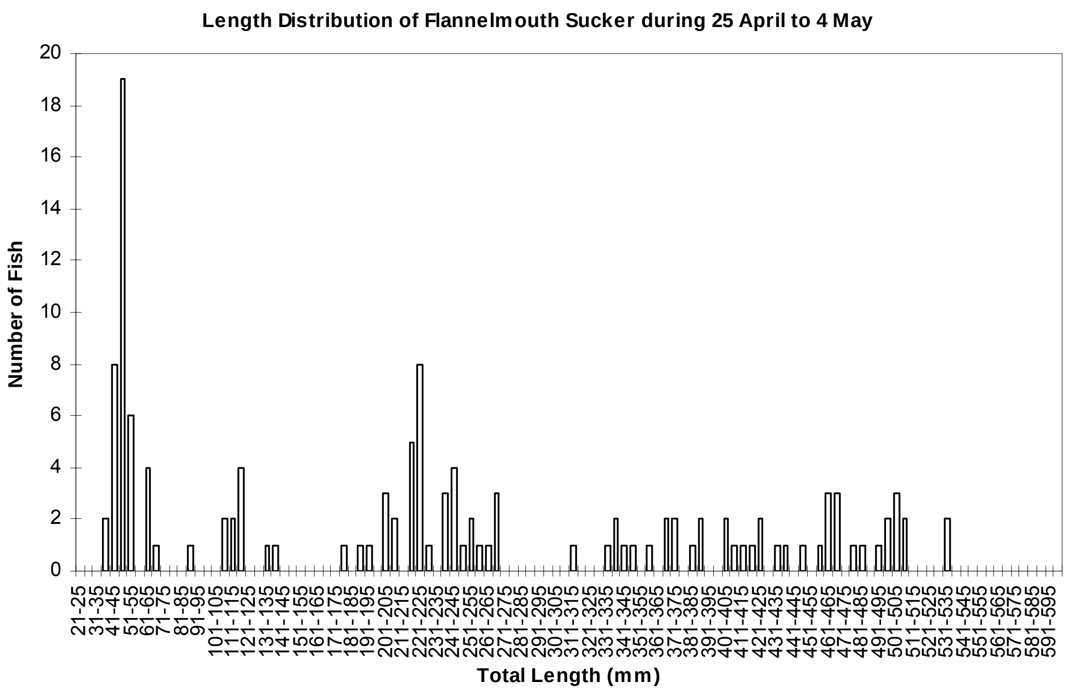
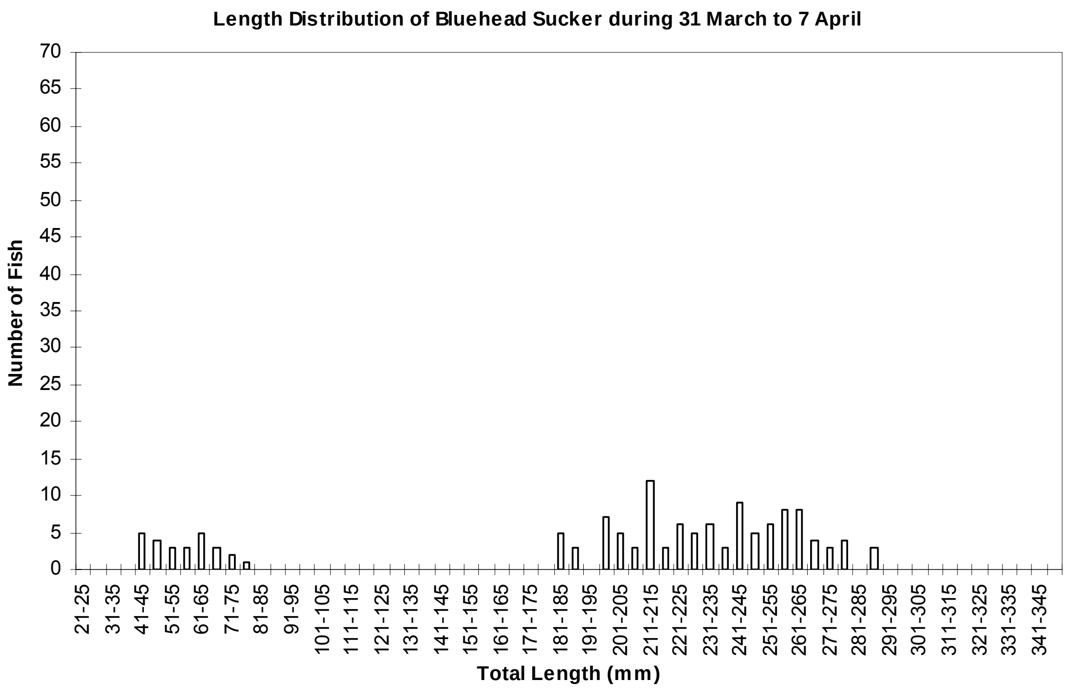


Figure 7 . Length frequency distribution of all flannelmouth sucker captured; Little Colorado River, spring 2006.



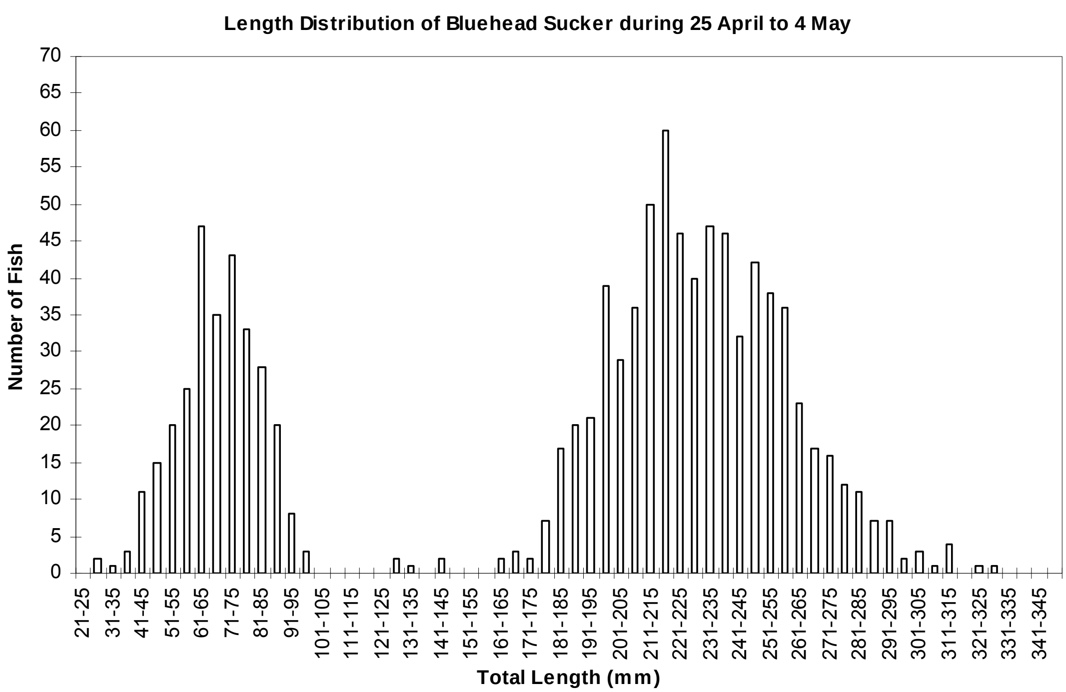
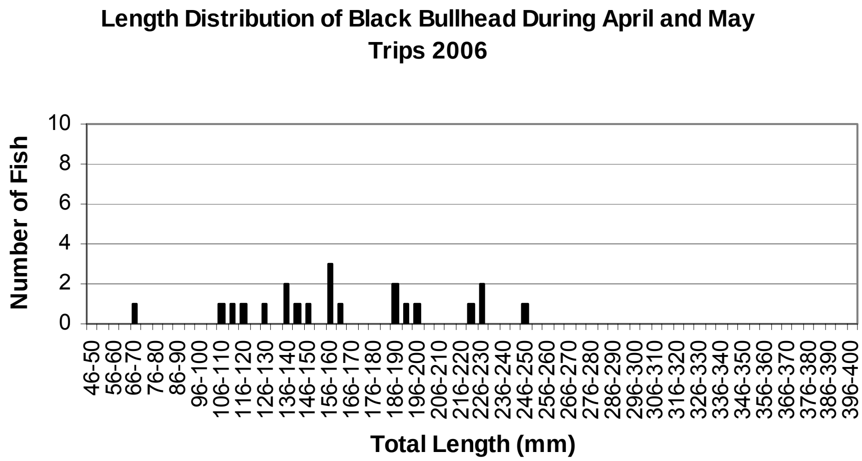
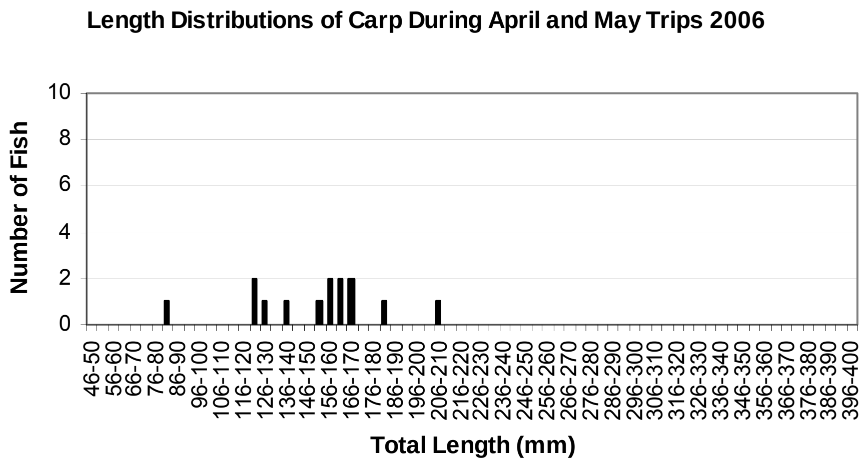


Figure 8. Length frequency distributions of all bluehead sucker captured; Little Colorado River, spring 2006.





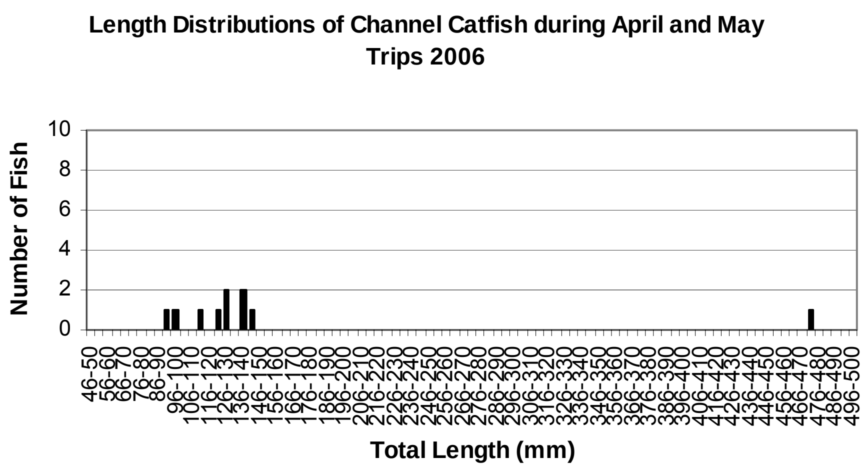
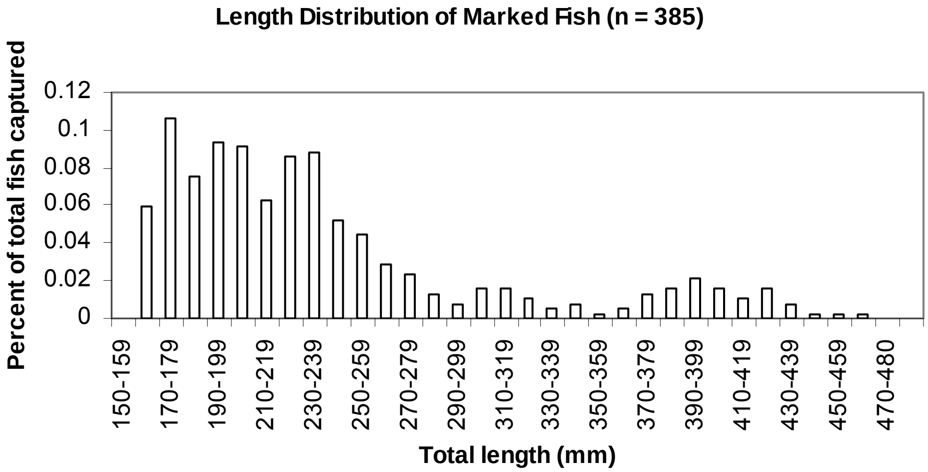
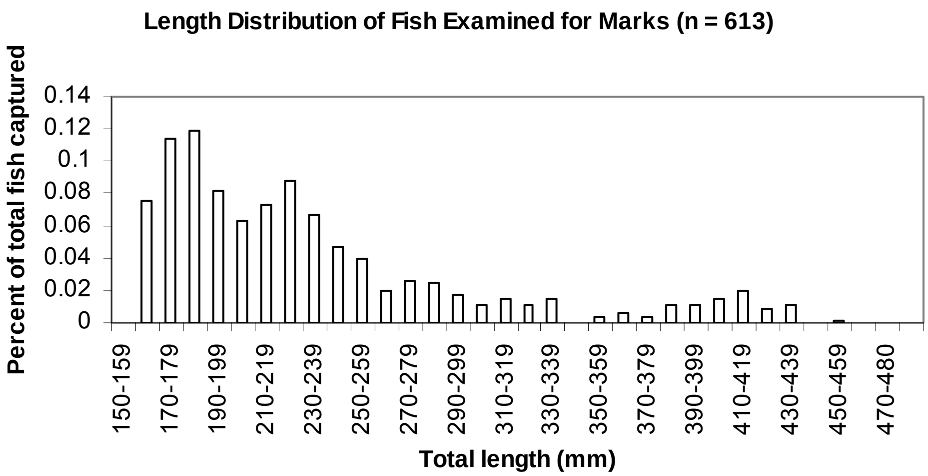


Figure 9. Length frequency distributions of black bullhead, carp and channel catfish during spring 2006; Little Colorado River.





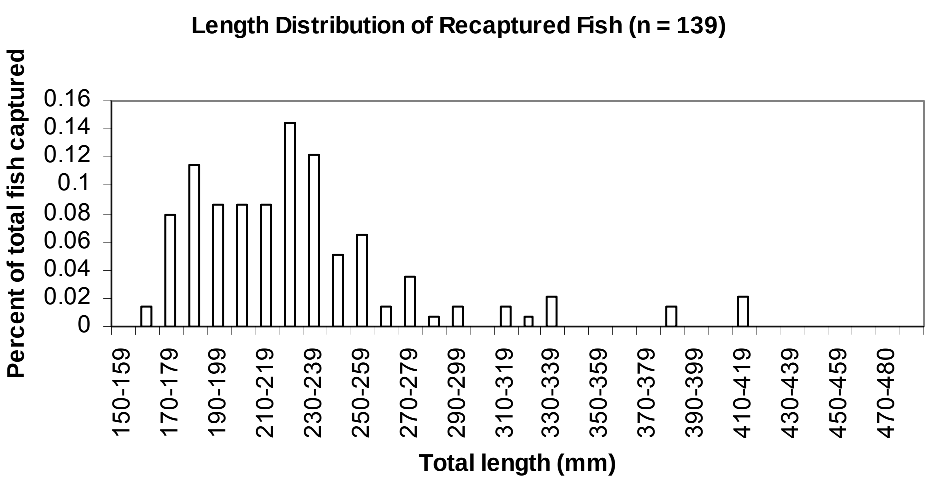
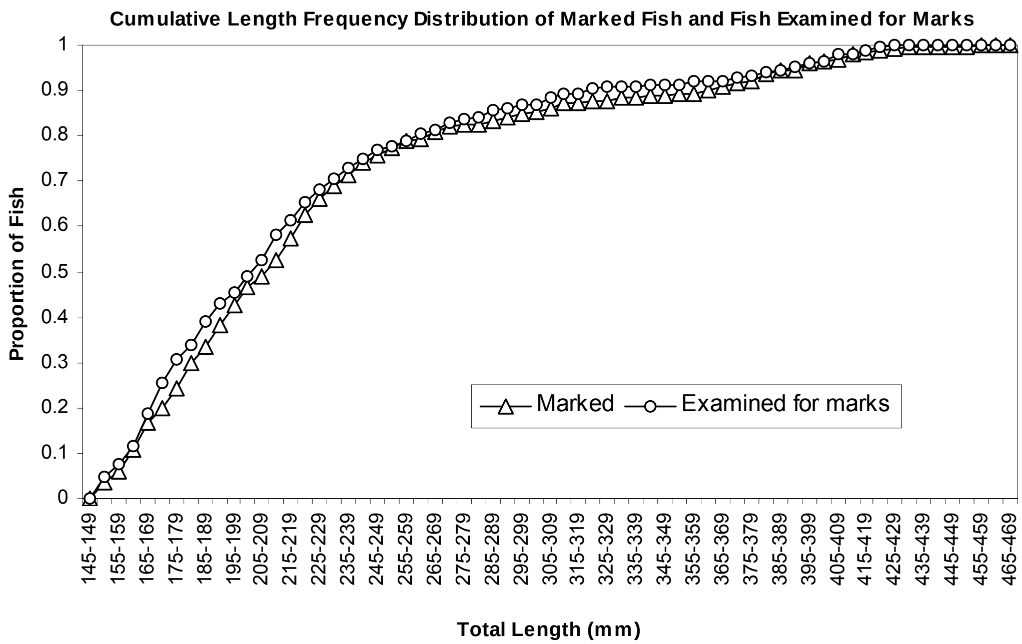


Figure 10. Length frequency distributions (shown as percentage of total) of all humpback chub ≥ 150 mm captured during the marking and recapture events; Little Colorado River, spring 2006.



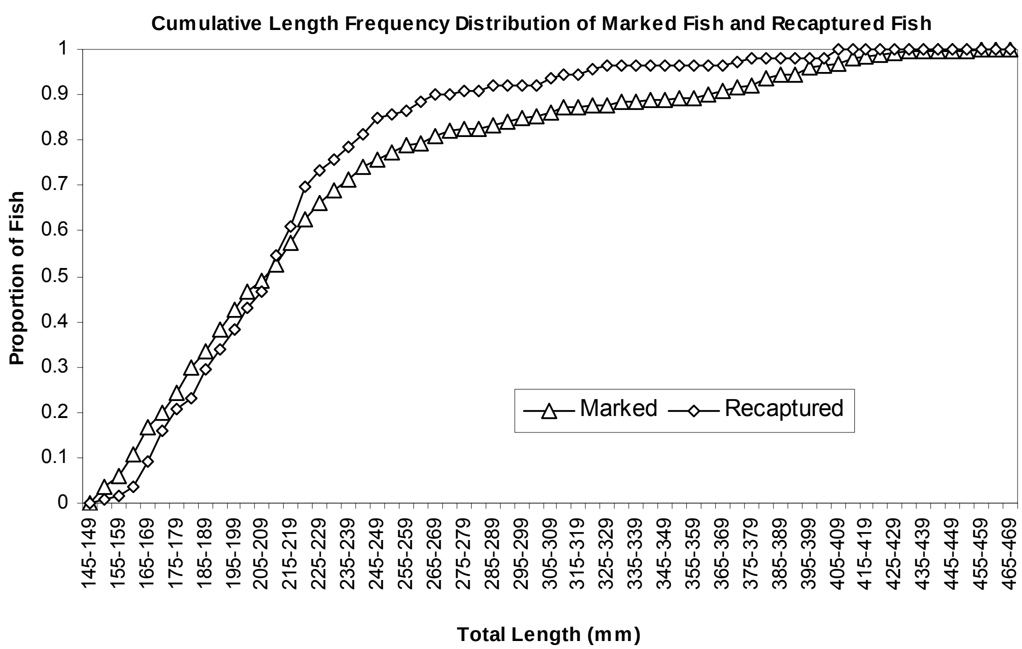


Figure 11. Cumulative length frequency distributions of humpback chub ≥ 150 mm captured; Little Colorado River, spring 2006.

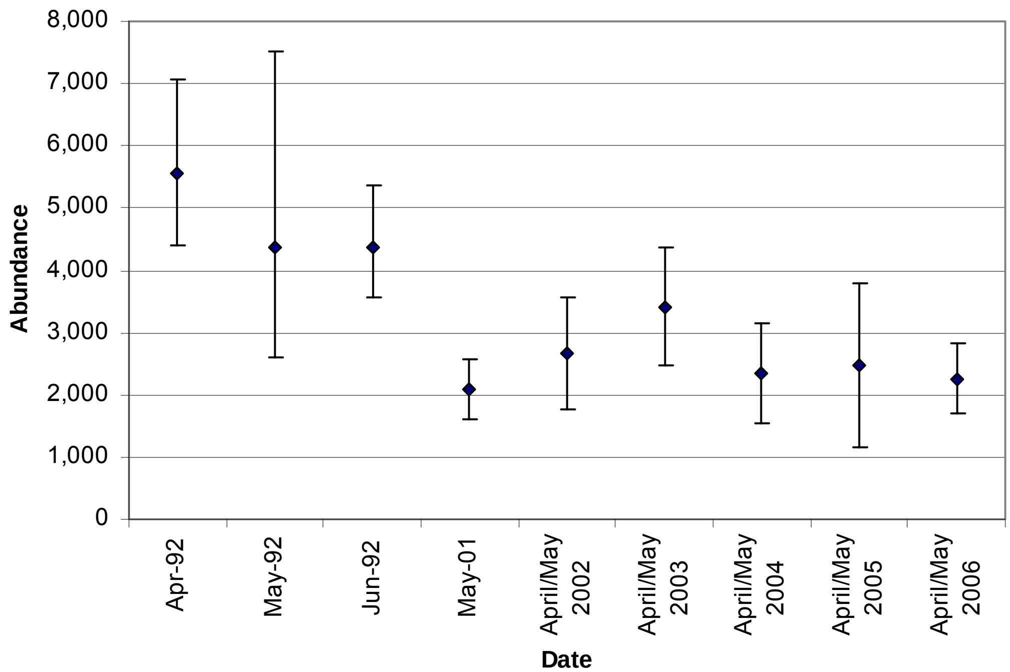


Figure 12. Spring abundance estimates of humpback chub ≥ 150 mm.

1992 estimates are from Douglas and Marsh (1996); 2001 estimate is from Van Haverbeke and Coggins (2002), 2002 estimate is from Van Haverbeke (2003), 2003 estimate is from Van Haverbeke (2004), 2004 estimate is from Van Haverbeke (2005), 2005 estimate is from Van Haverbeke (2006).

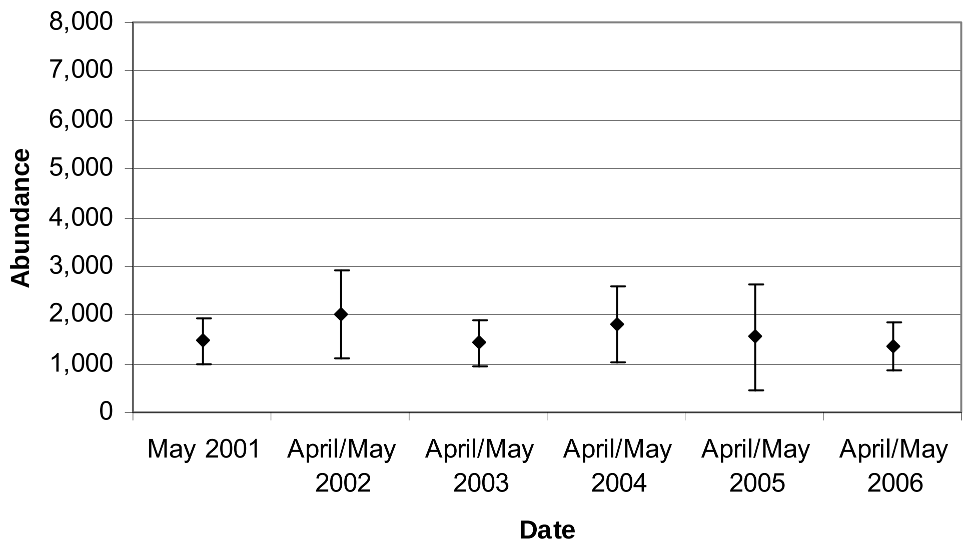


Figure 13. Spring abundance estimates of humpback chub ≥ 200 mm.

2001 estimate is from Van Haverbeke and Coggins (2002), 2002 estimate is from Van Haverbeke (2003), 2003 estimate is from Van Haverbeke (2004), 2004 estimate is from Van Haverbeke (2005), 2005 estimate is from Van Haverbeke (2006).

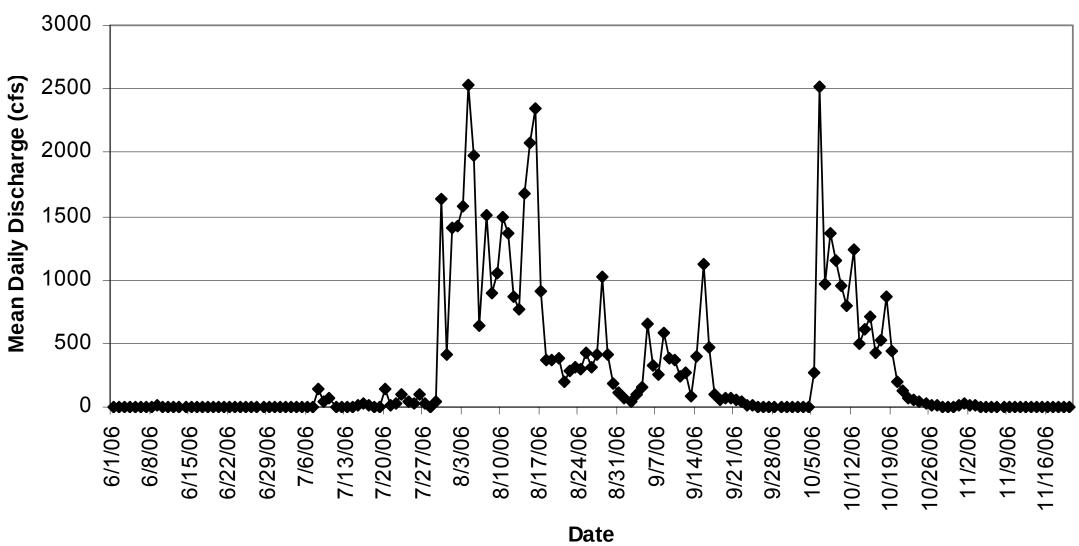
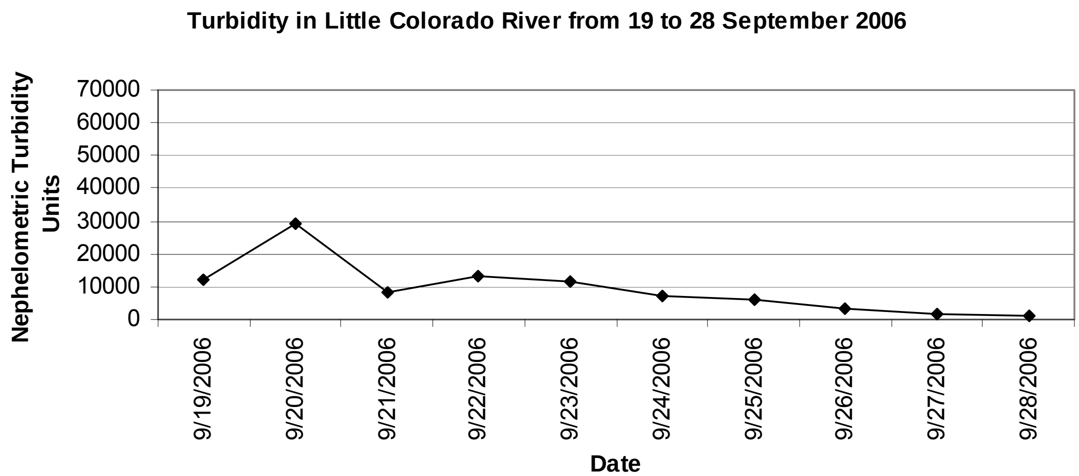


Figure 14. Provisional mean daily discharge (cubic feet/second; cfs) from USGS gage station 0904200; Little Colorado River, Arizona.



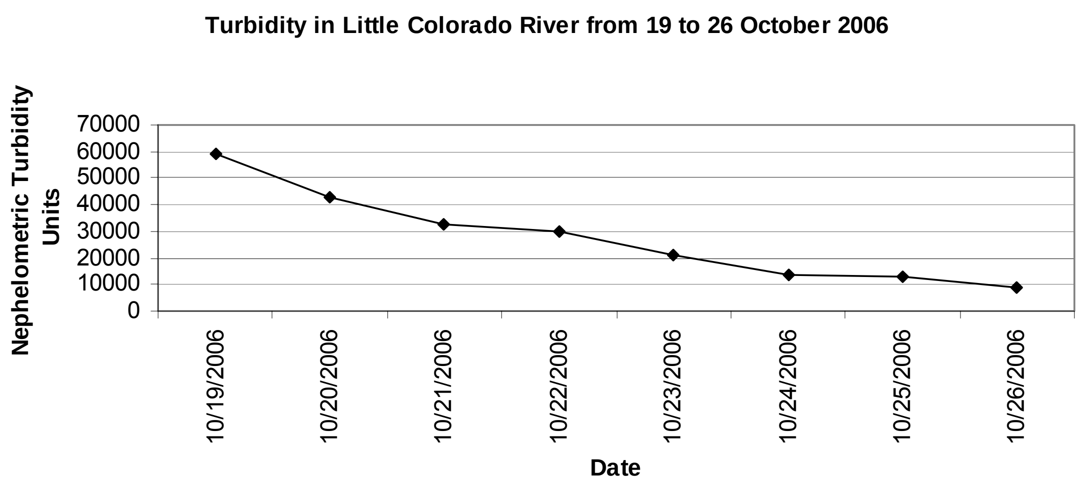
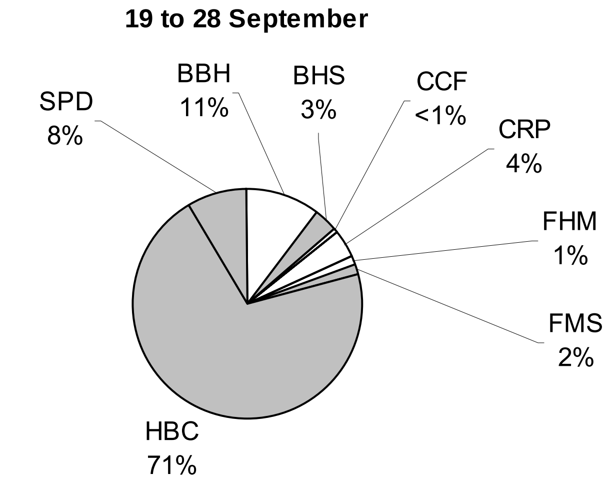


Figure 15. Turbidity readings taken during fall 2006; Little Colorado River.



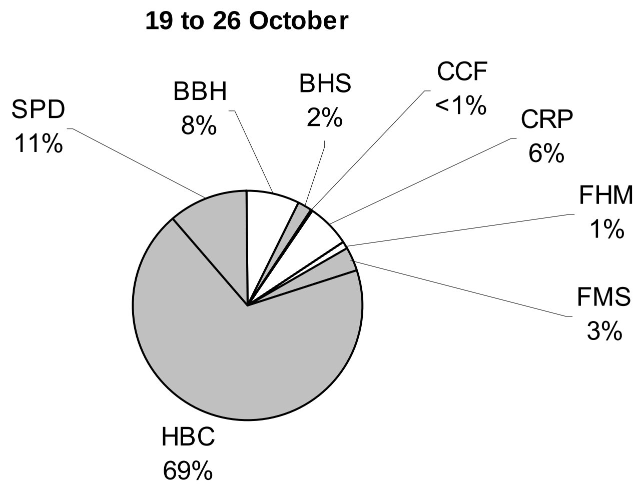
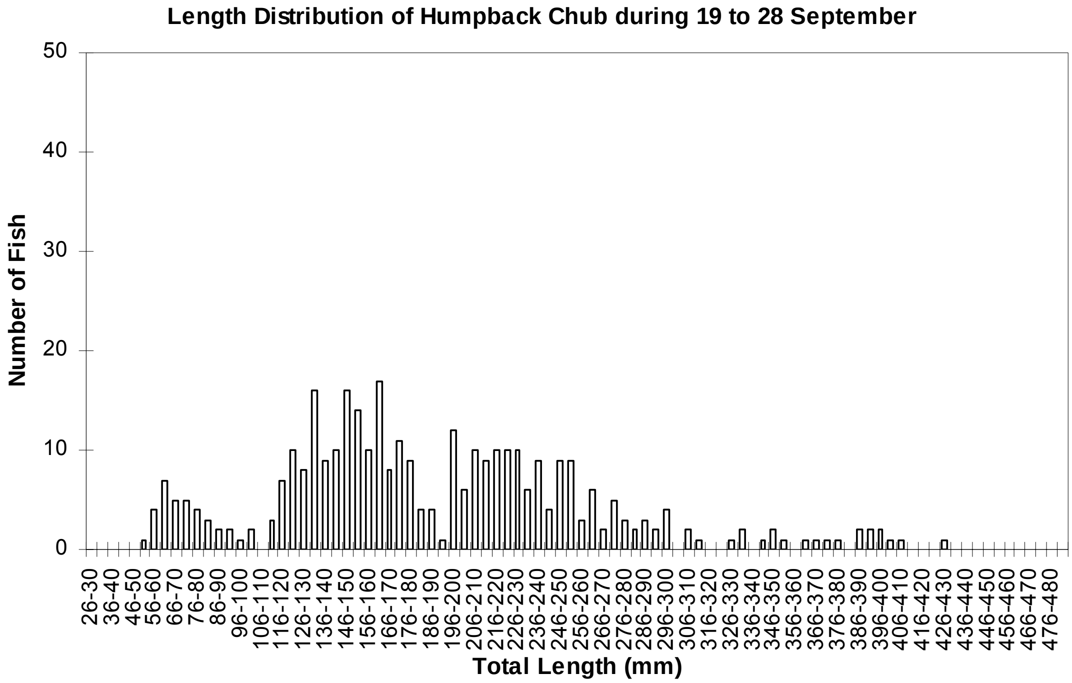


Figure 16. Observed species comparisons of fish captured. Shaded portions are native fish; Little Colorado River, fall 2006.

BBH = black bullhead (*Ameiurus melas*); BHS = bluehead sucker (*Catostomus discobolus*); CCF=channel catfish (*Ictalurus punctatus*); CRP = common carp (*Cyprinus carpio*); FHM = fathead minnow (*Pimephales promelas*); FMS = flannelmouth sucker (*Catostomus latipinnis*); HBC = humpback chub (*Gila cypha*); SPD = speckled dace (*Rhinichthys osculus*).



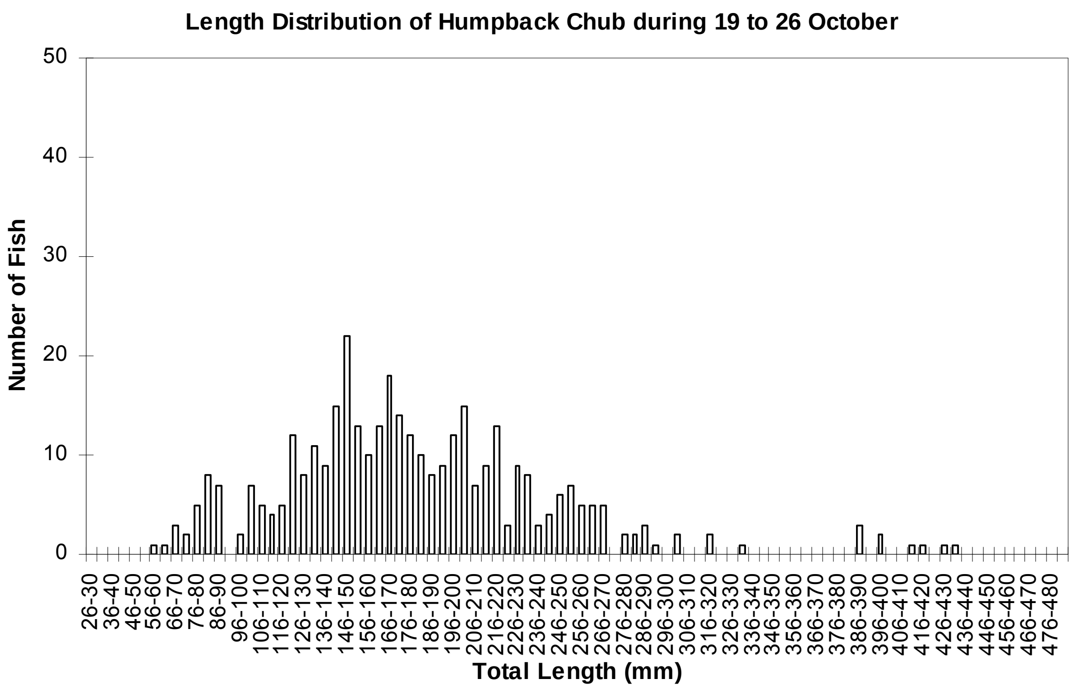
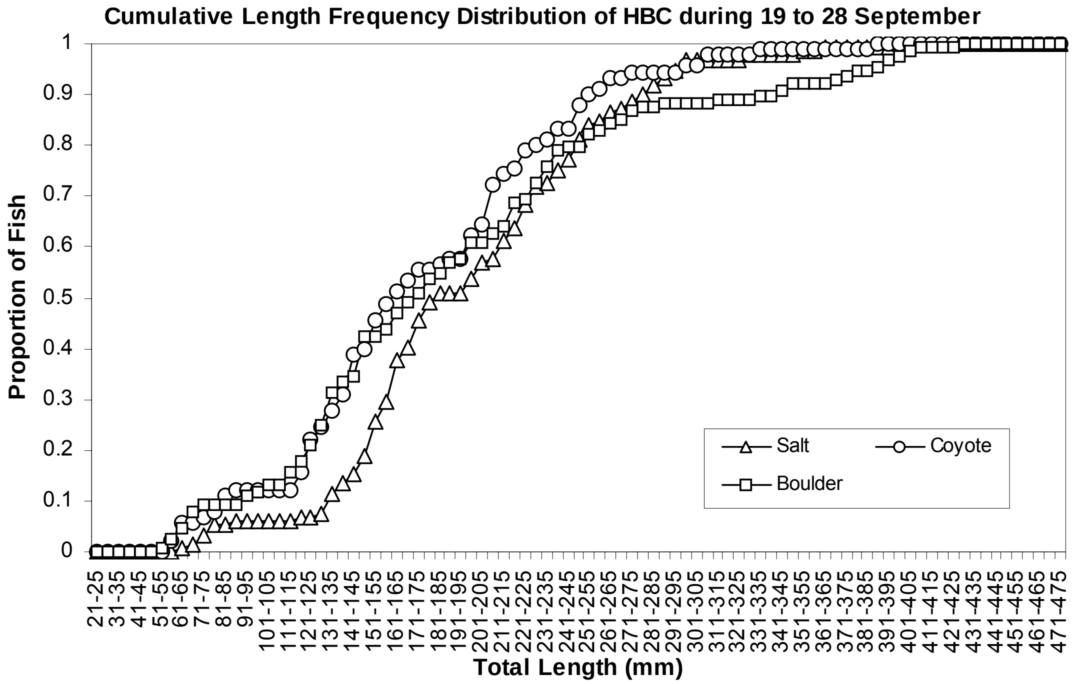


Figure 17. Length frequency distributions of all humpback chub captured; Little Colorado River, fall 2006.



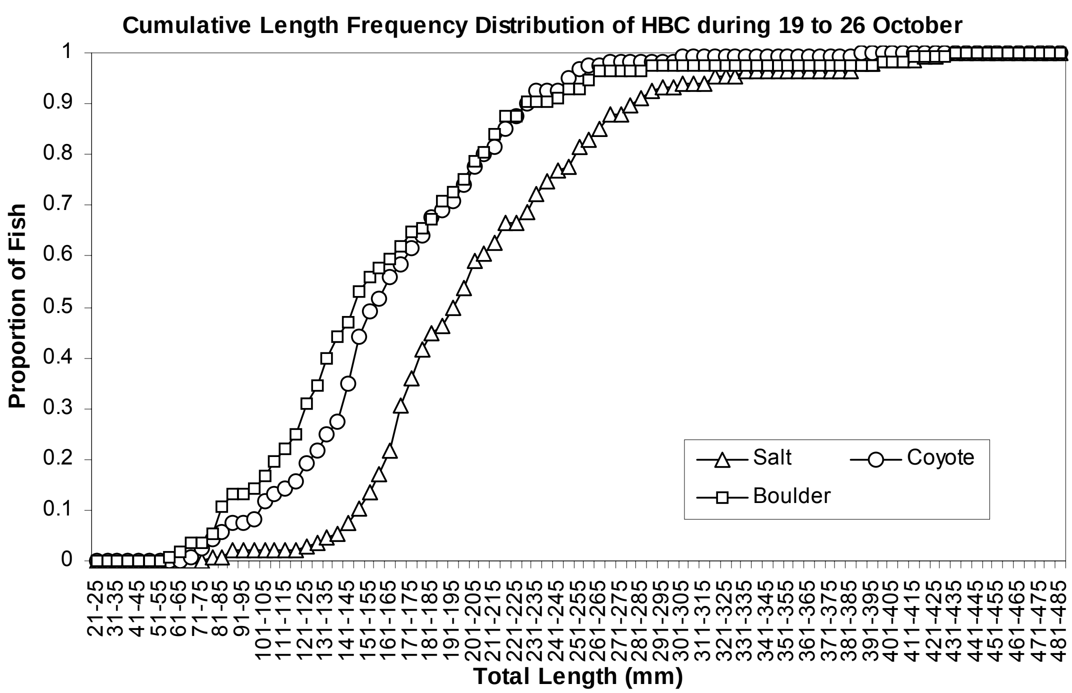


Figure 18. Cumulative length frequencies of all humpback chub captured in Salt, Coyote and Boulders reaches; Little Colorado River, fall 2006.

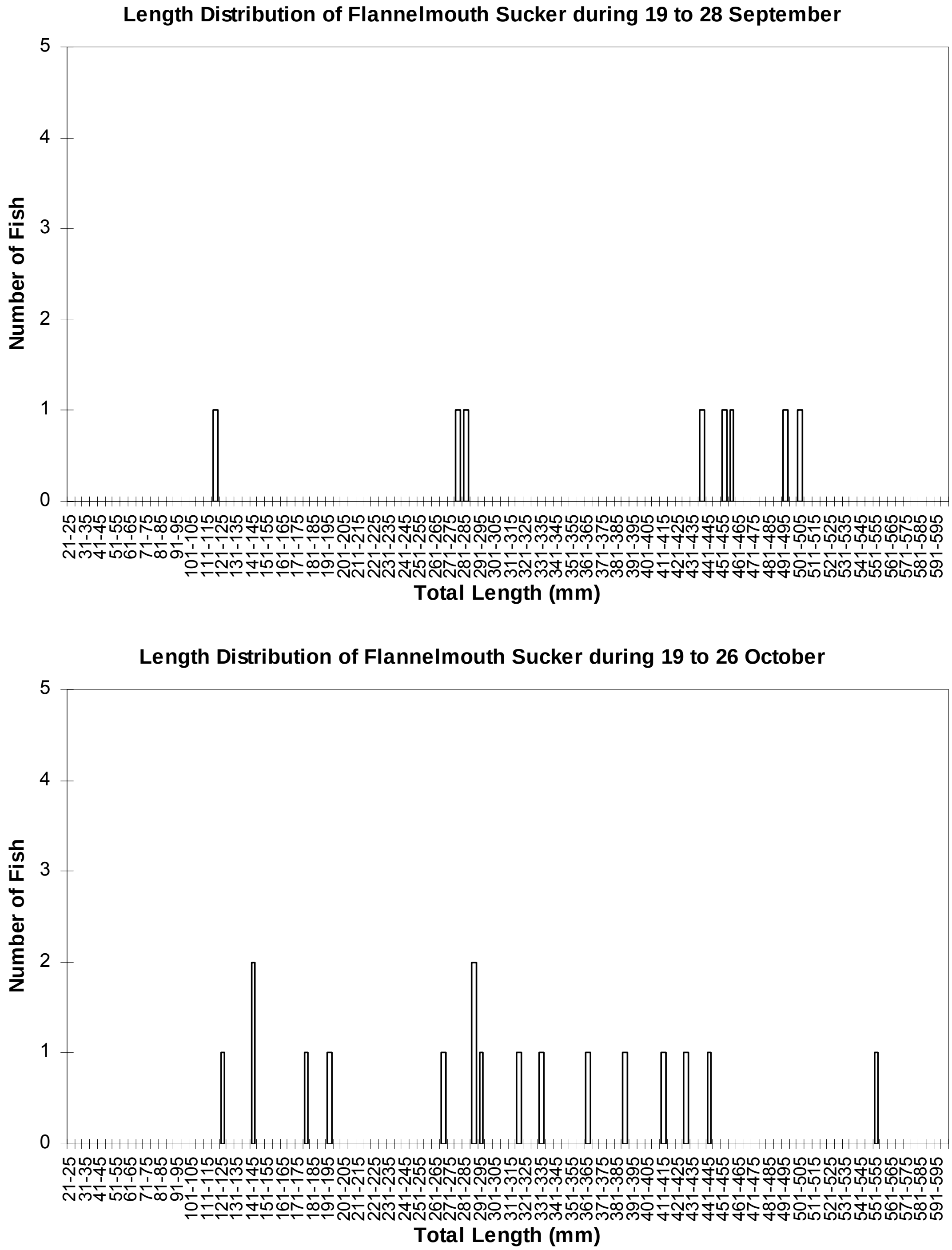
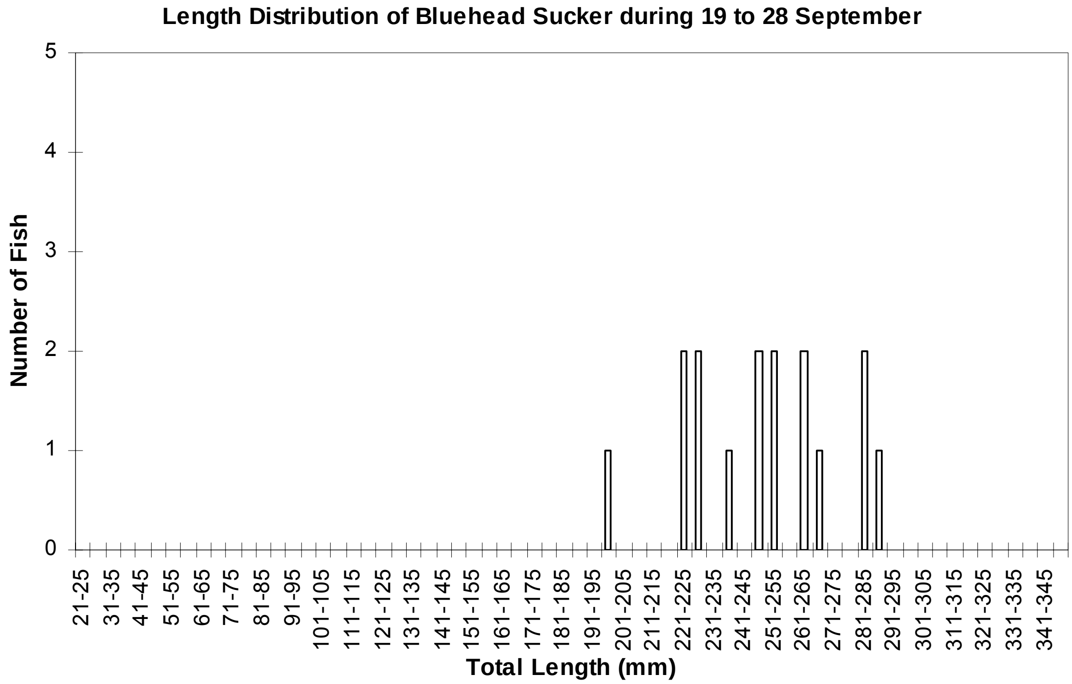


Figure 19 . Length frequency distributions of all flannelmouth sucker captured; Little Colorado River, fall 2006.



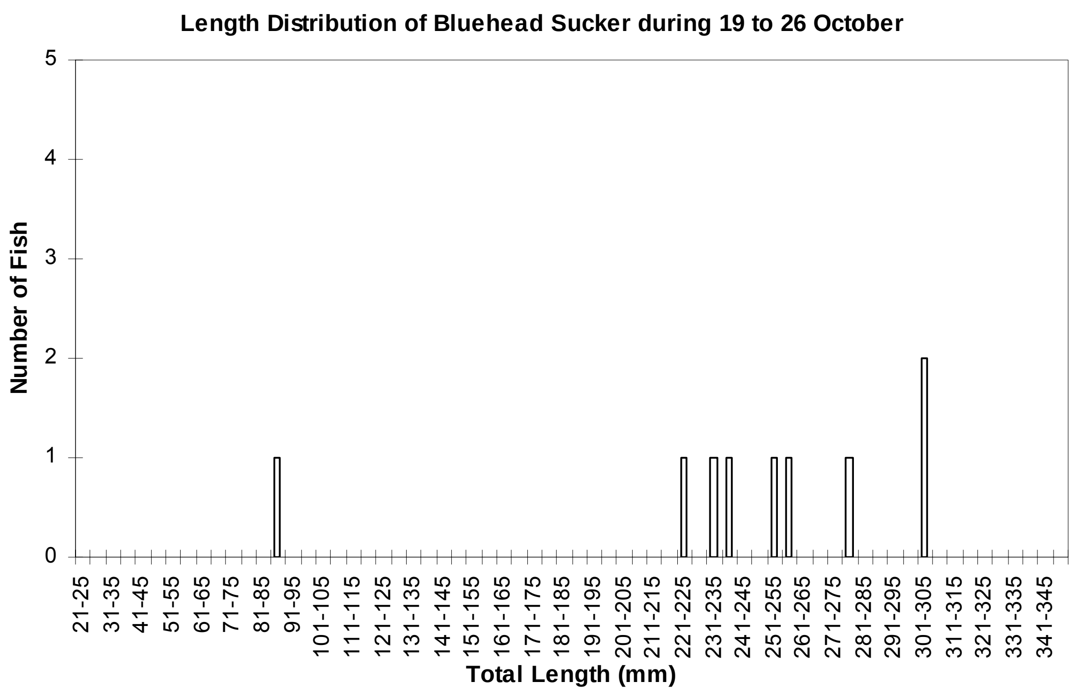
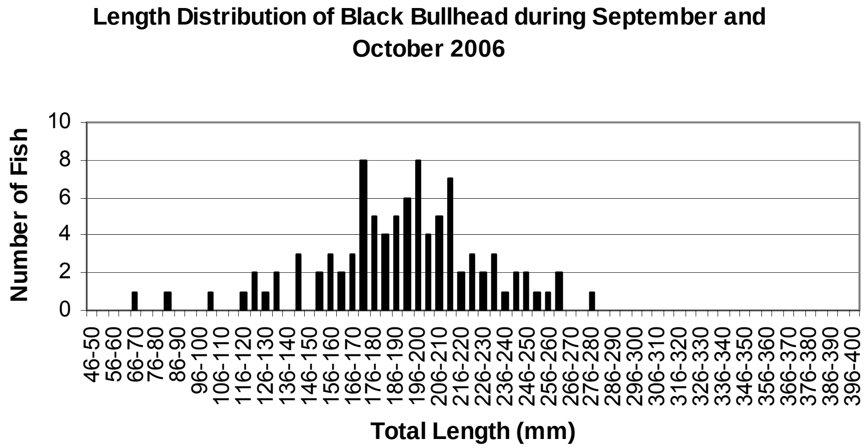
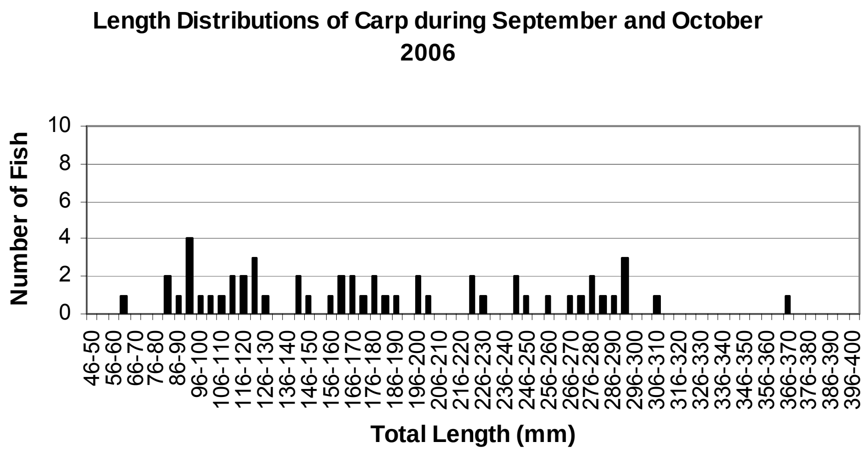


Figure 20 . Length frequency distributions of all bluehead sucker captured; Little Colorado River, fall 2006.





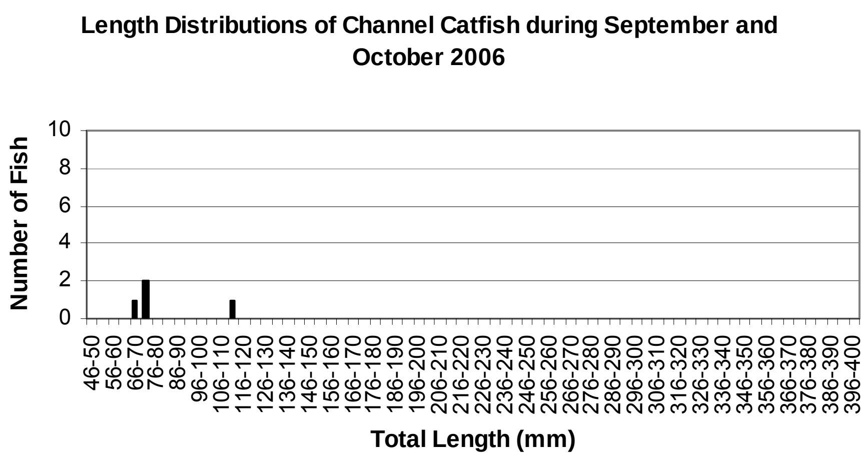


Figure 21. Length frequency distributions for black bullhead, channel catfish, and common carp. Little Colorado River, fall 2006.

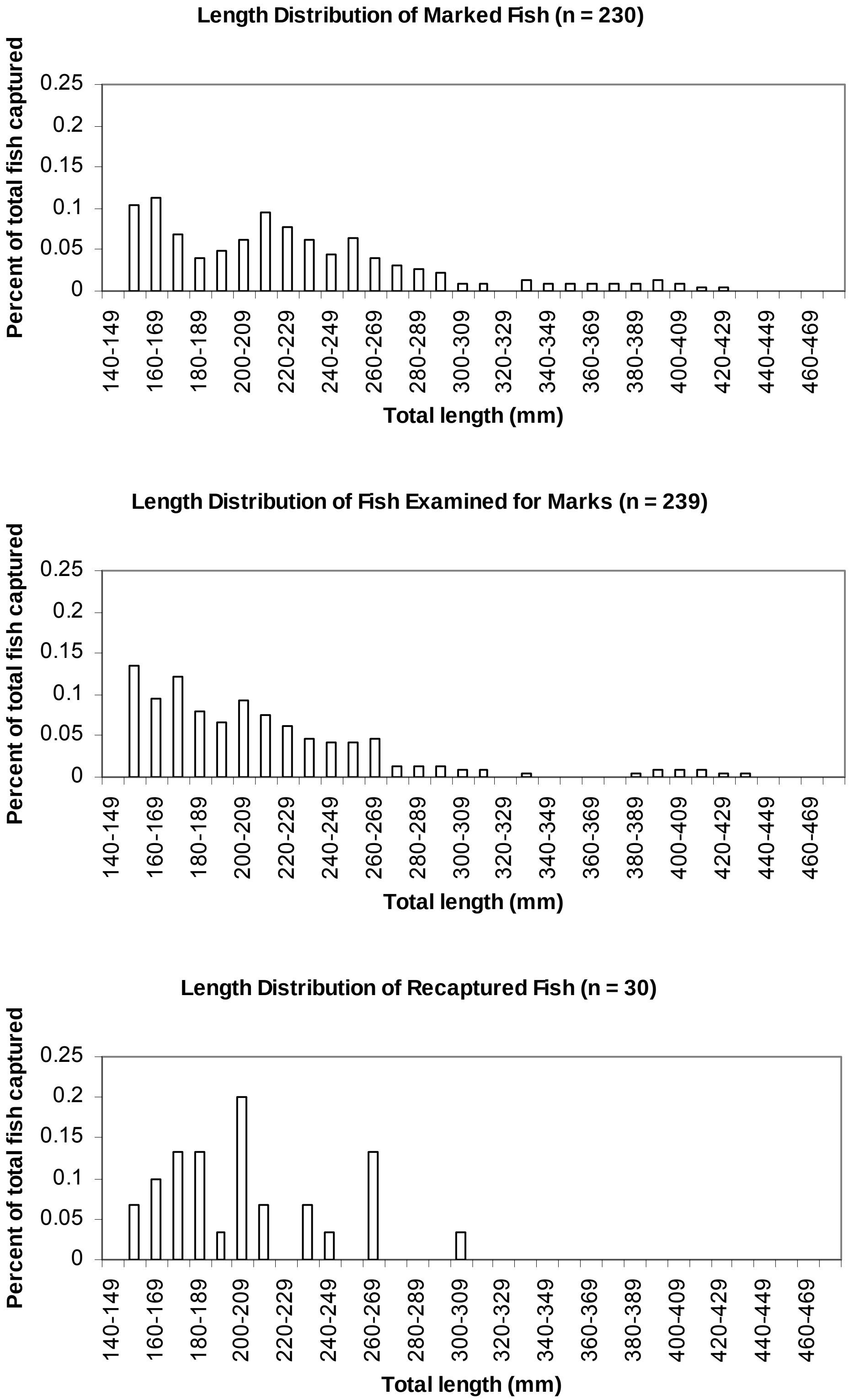
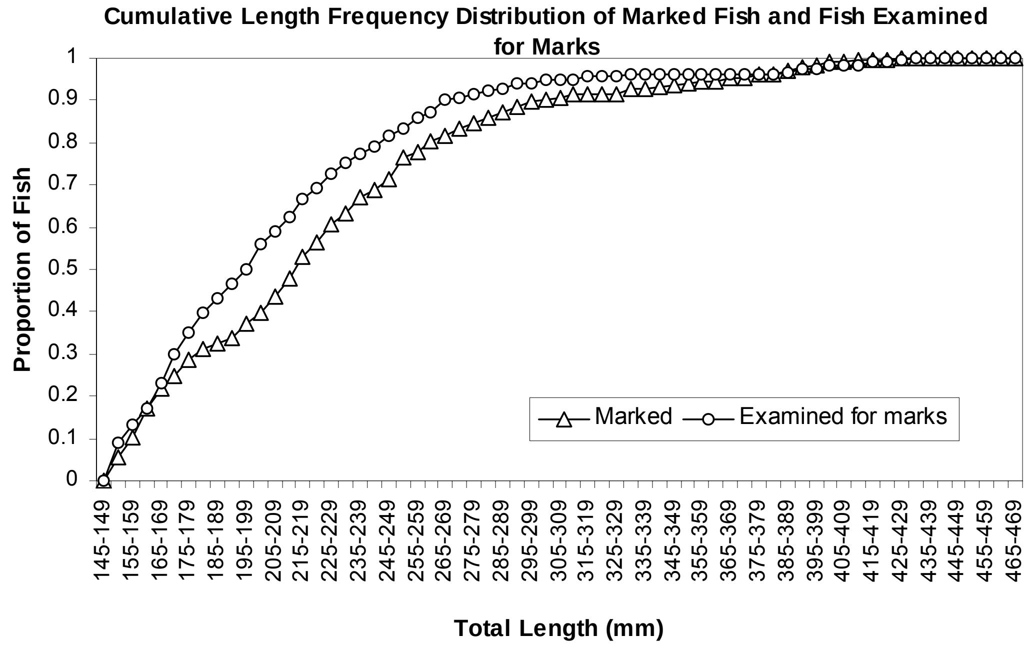


Figure 22. Length frequency distributions (shown as percentage of total) of all humpback chub ≥ 150 mm captured during the marking and recapture events; Little Colorado River, fall 2006.



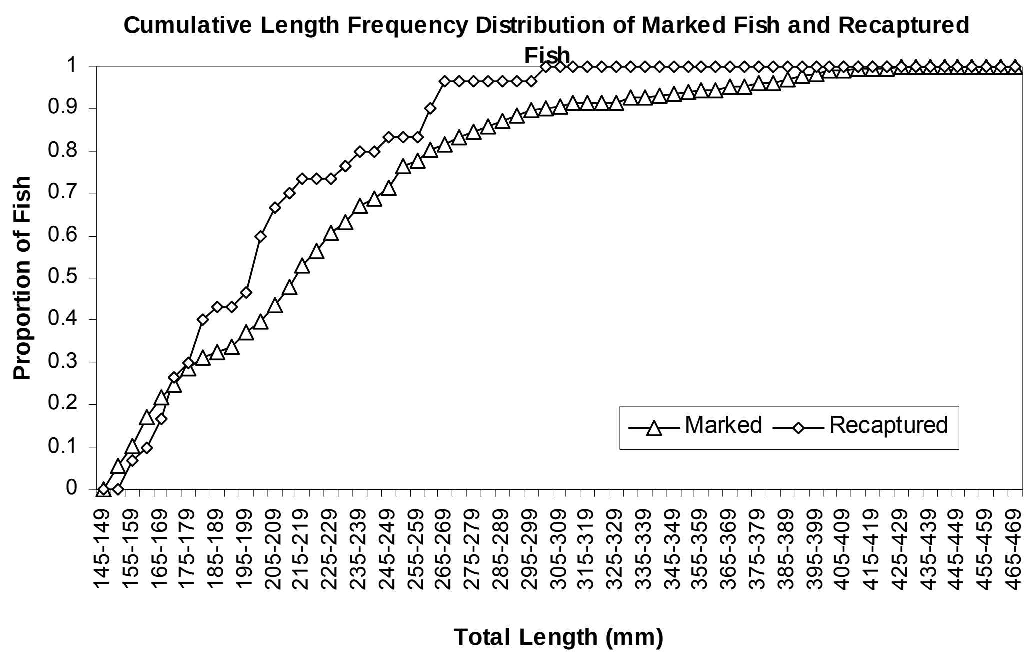


Figure 23. Cumulative length frequency distributions of humpback chub ≥ 150 mm; Little Colorado River, fall 2006.

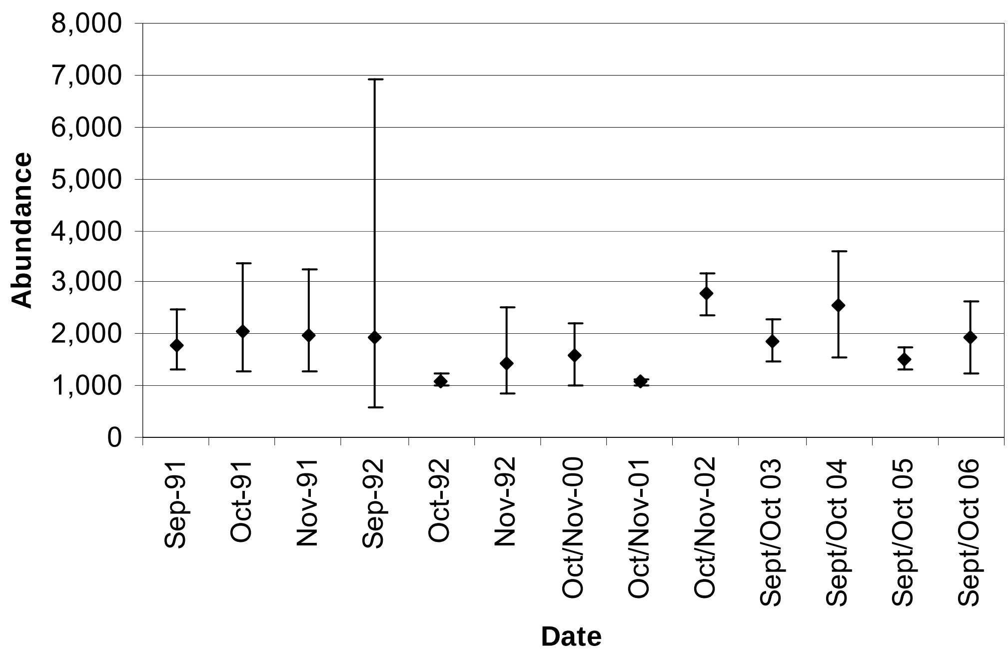


Figure 24. Fall abundance estimates of humpback chub ≥ 150 mm.

1991 and 1992 estimates are from Douglas and Marsh (1996); 2000 estimate is from Coggins and Van Haverbeke (2001), 2001 estimate is from Van Haverbeke and Coggins (2002), 2002 estimate is from (Van Haverbeke (2003), 2003 estimate from Van Haverbeke (2004), 2004 estimate from Van Haverbeke (2005), 2005 estimate is from Van Haverbeke (2006).

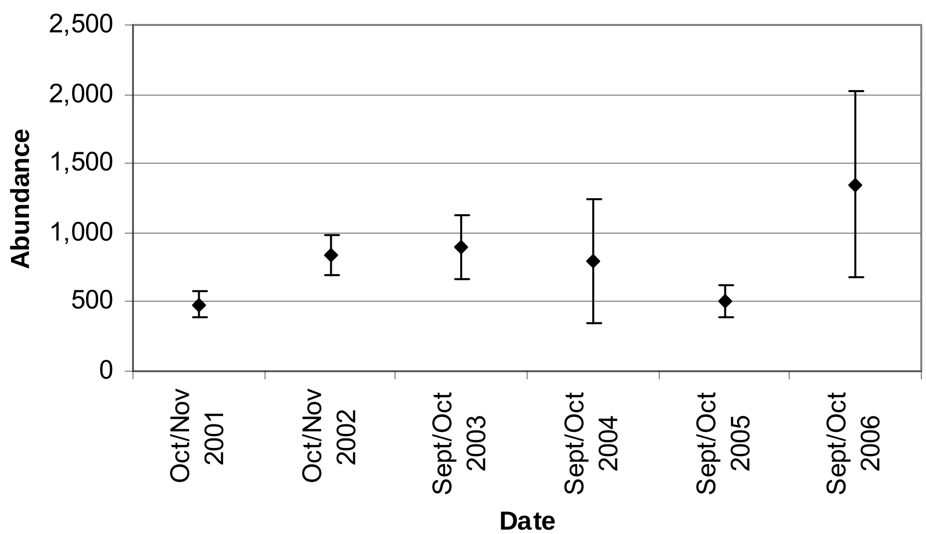


Figure 25. Fall abundance estimate of humpback chub ≥ 200 mm.

2001 estimate is from Van Haverbeke and Coggins (2003), 2002 estimate is from (Van Haverbeke (2003), 2003 estimate from Van Haverbeke (2004), 2005 estimate is from Van Haverbeke (2006).

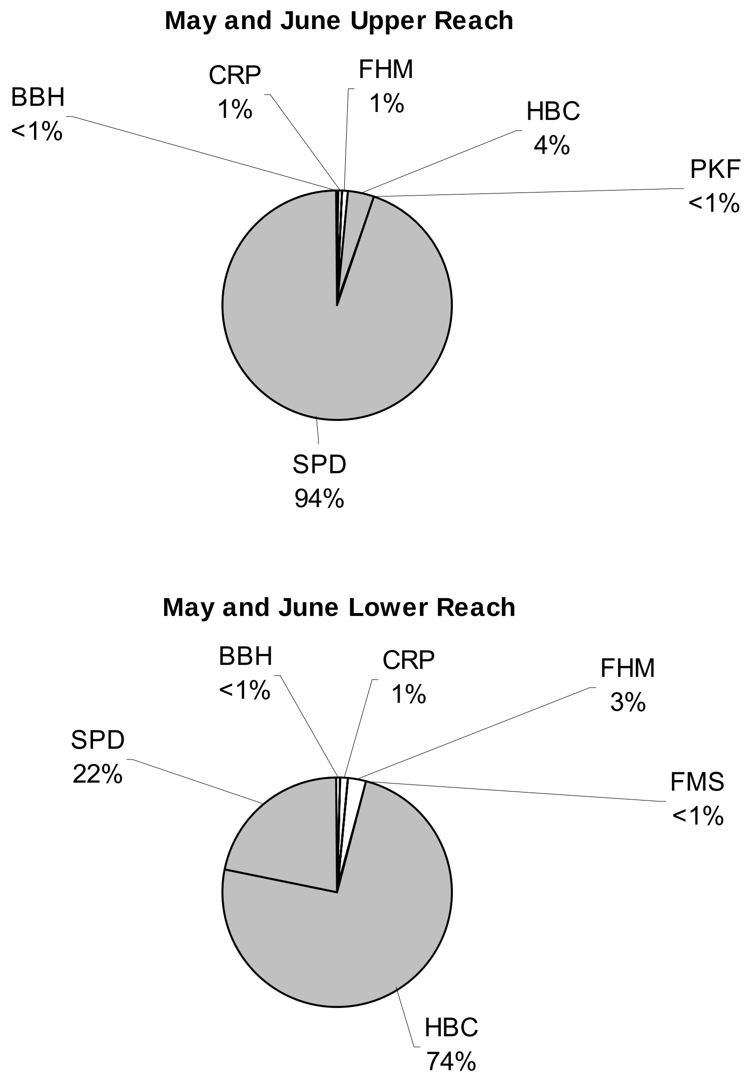


Figure 26. Observed species compositions of all fish captures above Chute Falls (14.1-18.1 rkm), and below Chute Falls (13.67 to 14.1 rkm). Shaded portions are native fish; Little Colorado River, 2006.

BBH = black bullhead (*Ameiurus melas*); CRP = common carp (*Cyprinus carpio*); FHM = fathead minnow (*Pimephales promelas*); FMS = flannelmouth sucker (*Catostomus latipinnis*); HBC = humpback chub (*Gila cypha*); SPD = speckled dace (*Rhinichthys osculus*).

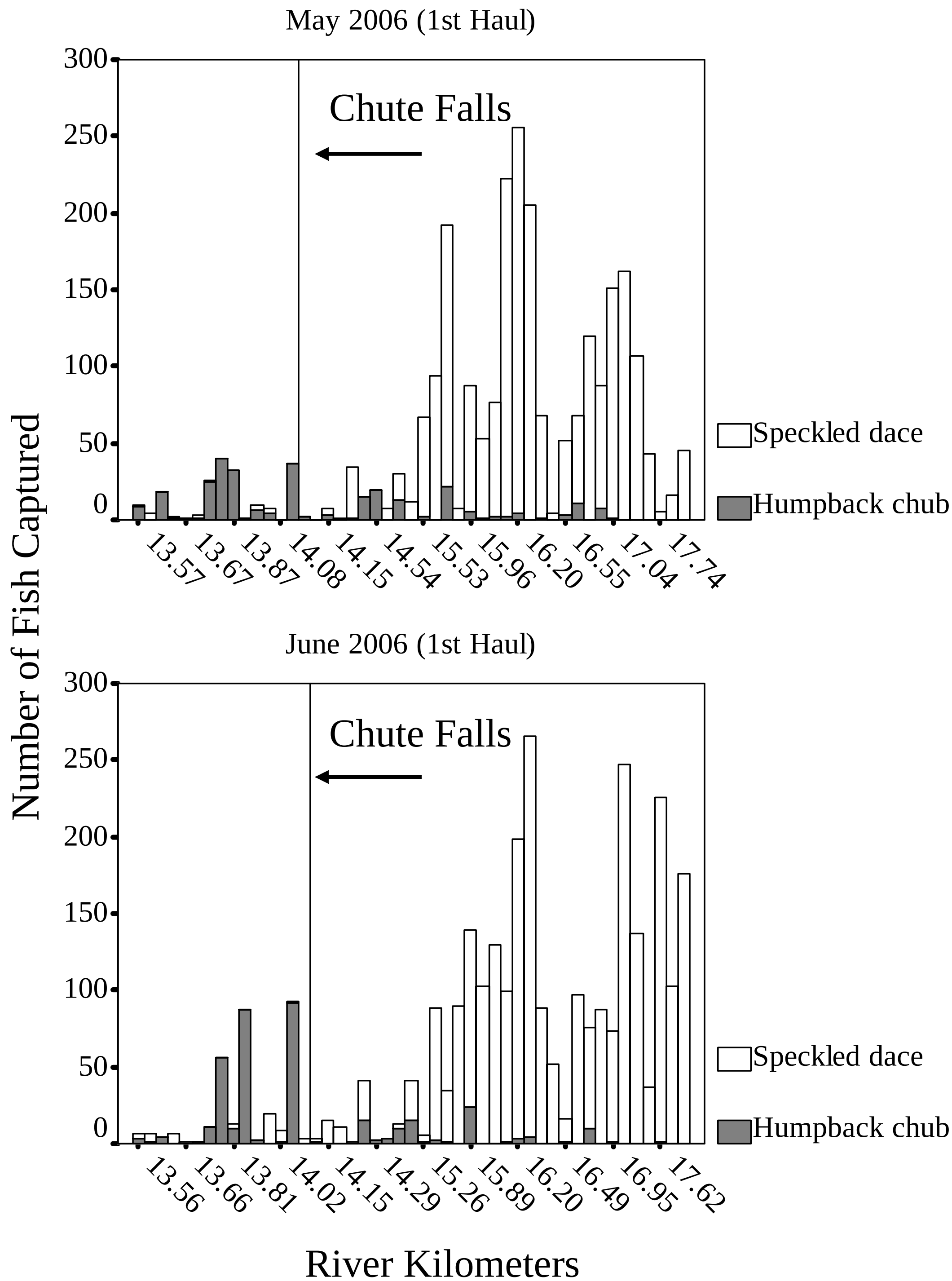
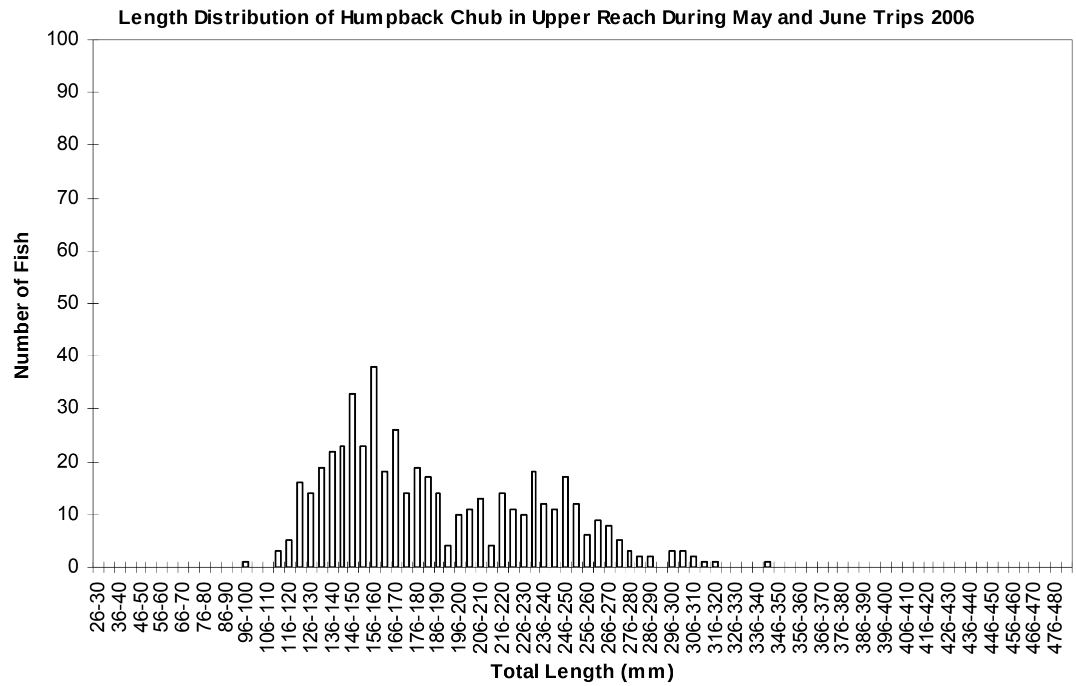


Figure 27. Numbers of unique humpback chub and speckled dace captured during the first 24 h haul of hoop nets deployed between 13.57 and 18.1 river kilometers. The lower and upper study reaches were separated by Chute Falls; Little Colorado River, 2006.



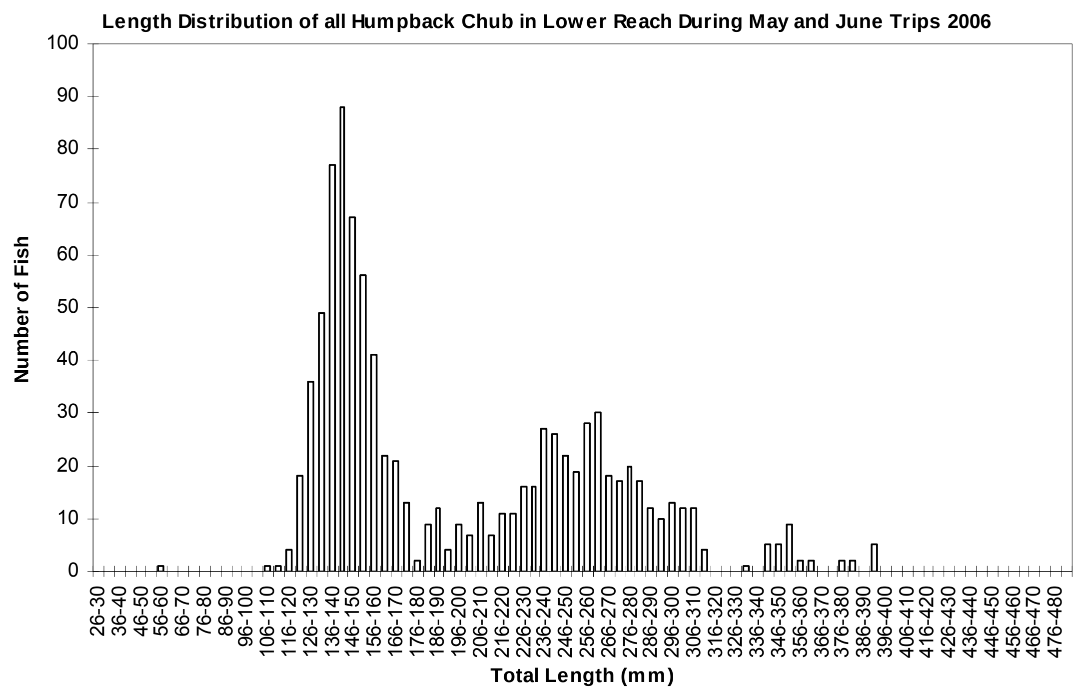


Figure 28. Length frequency distributions of all humpback chub captured above Chute Falls (14.1 to 18.1 rkm), and below Chute Falls (13.67 to 14.1 rkm) during the May and June; Little Colorado River, 2006.

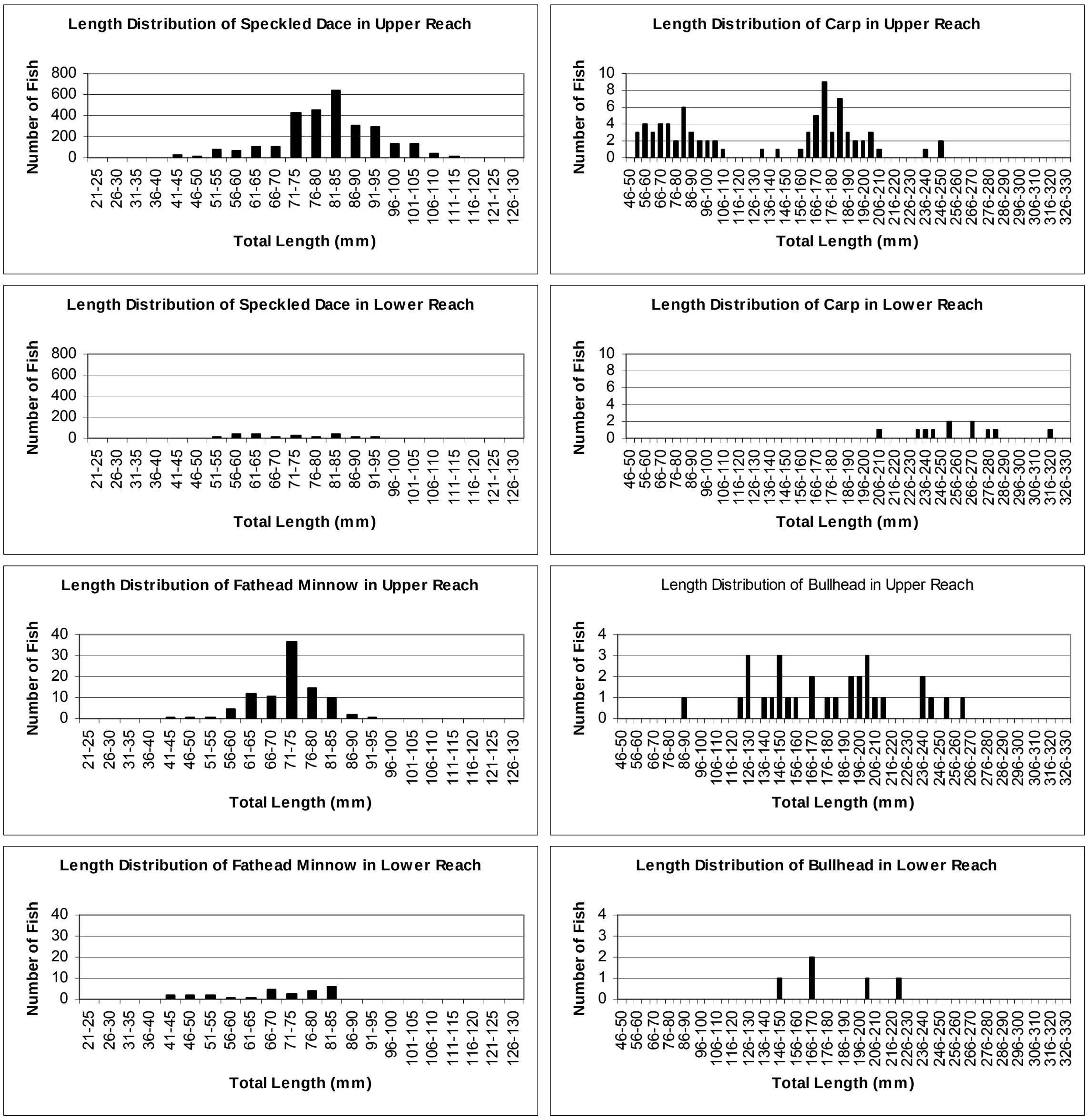


Figure 29. Length frequency distributions of speckled dace, carp, fathead minnow and black bullhead above Chute Falls (14.1 to 18.1 rkm), and below Chute Falls (13.67 to 14.1 rkm) during the May and June monitoring trips; Little Colorado River, 2006.

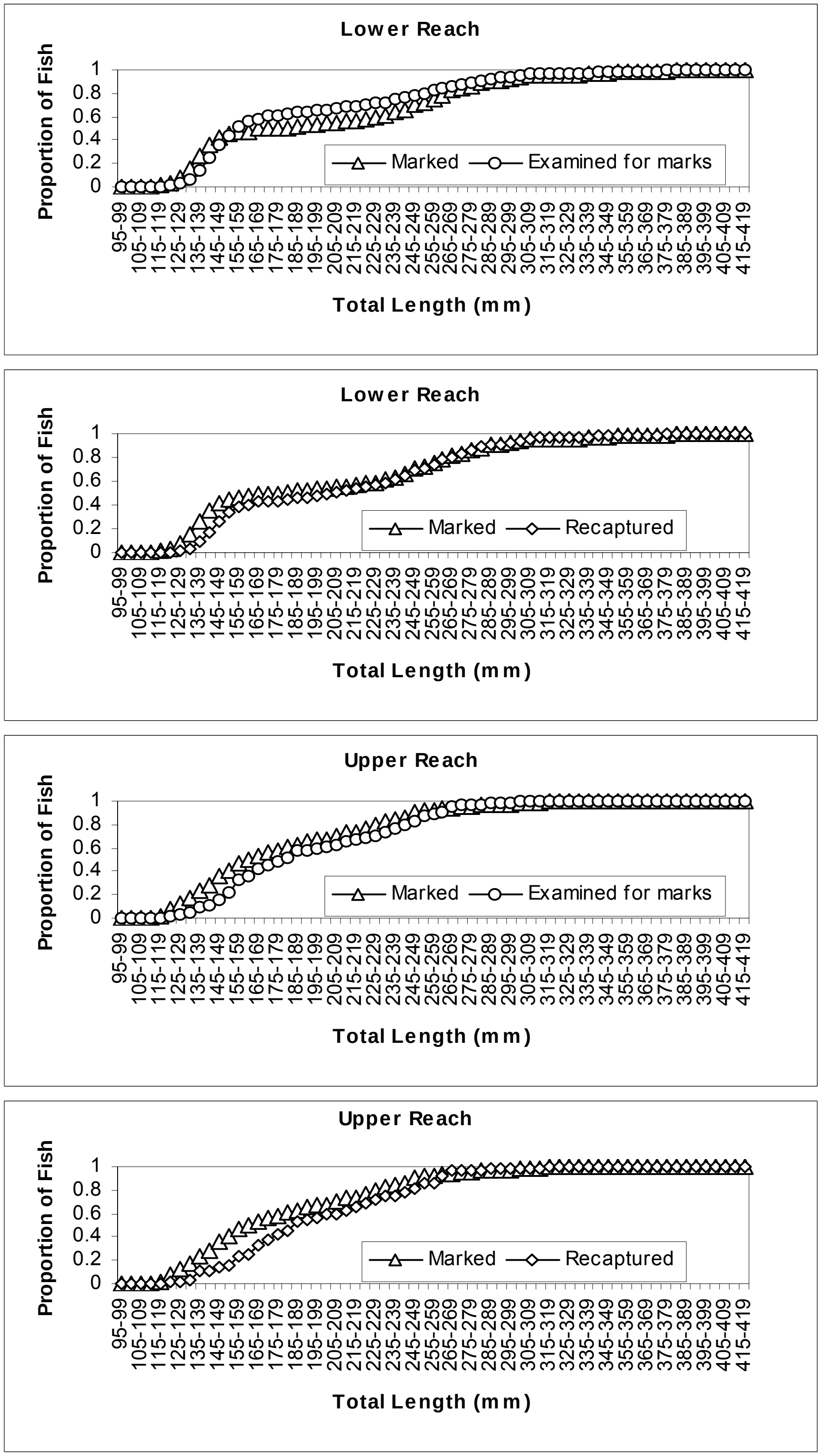


Figure 30. Cumulative length frequency distributions of humpback chub ≥ 100 mm; Little Colorado River, 2006.